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Qazvin Seminar on

Selective coordination of power systems

Tehran, 26 –27 January 2008

Lecturer:
Gerhard Ziegler
Siemens Erlangen

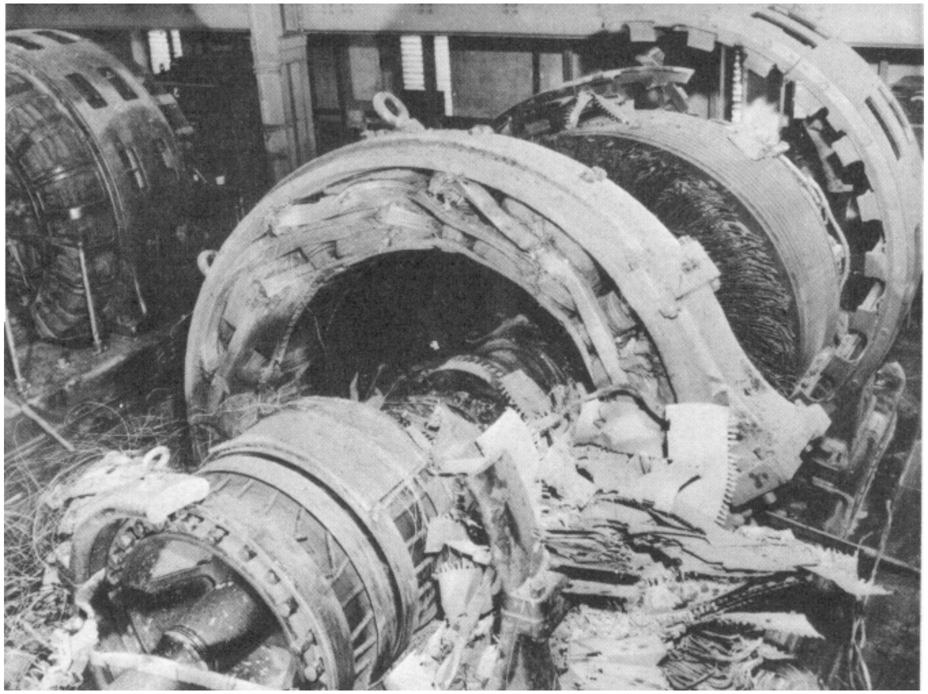
Seminar Contents:

1. Tasks and principles of power system protection
2. Typical protection schemes
3. Protection of MV and LV Distribution networks
4. Transformer protection
5. Basics of Current and Voltage transformers

Tasks and Principles of Power System Protection

Tasks of Power System Protection

Protection cannot prevent faults,



but:

- **minimise the consequences**

by:

- **fast and selective tripping of the faulted system component**
- **automatic reclosing in case of transient faults**
- **providing information for fast fault analysis and system restoration in case of permanent faults**

This would not have happened with appropriate protection!

Requirements on system protection

Fast **means**:

- As fast as necessary,
  i. e. tripping of short-circuit within the critical fault clearing time
  (z. B. <100 ms in transmission networks)
  to minimise damage and to ensure system stability

Reliable **means**:

- Reliable tripping in case of internal faults
  (high availability,no under-function)
- Reliable non-tripping, in case of load or external faults
  (high security, no over-function)

Selective means:

- Tripping of only faulty system components,
  leaving the healthy parts in service to continue energy supply

Negative example:
New York dark (1965 u. 1977)

Typical protection objects

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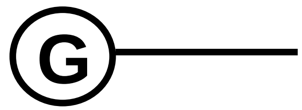
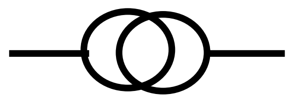
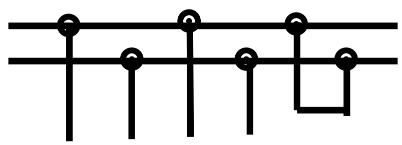
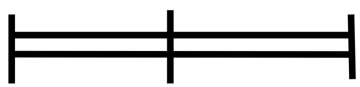
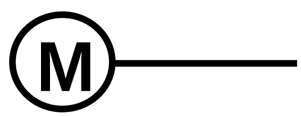
Generators		< 1MVA to 1500 MVA
Transformers		0,1 MVA to 1000 MVA
Busbars		MV to EHV
Lines		1kV to 750 kV
Motors		ca. 100 kW to ca. 20 MW

Fault current, influencing factors

(three phase short-circuit as an example)

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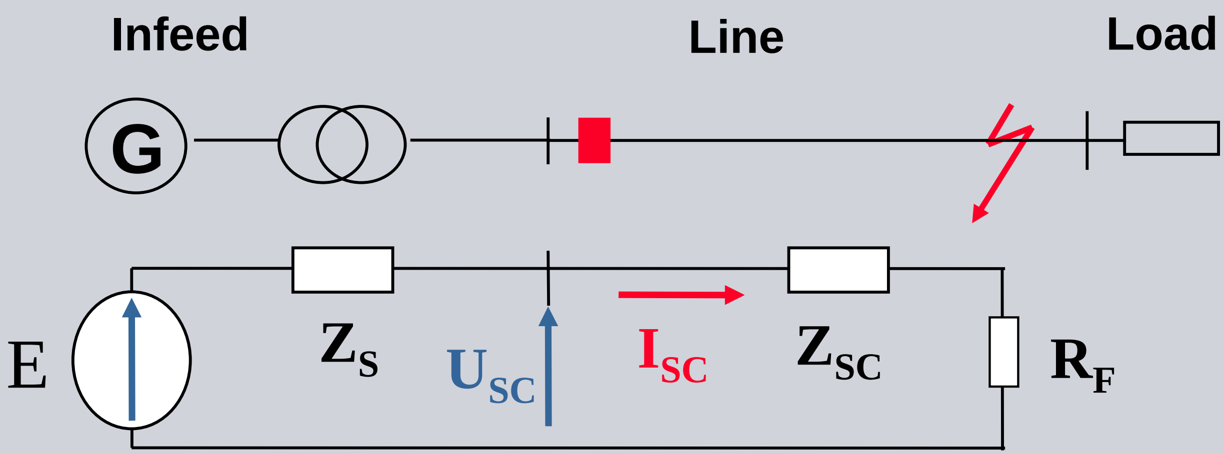


$$E = \frac{1{,}1 \times U_N}{\sqrt{3}} \qquad Z_S = \frac{{U_N}^2}{S_K''} \qquad Z_{SC} = z_L'[Ohm/km] \times l(km)$$

$$\underline{I}_{\text{SC-3-ph}} = \frac{\underline{E}}{\underline{Z}_S + \underline{Z}_{SC} + R_F}$$

Example (R_F neglected):

$$E = \frac{1{,}1 \times 110kV}{\sqrt{3}} = 70kV$$

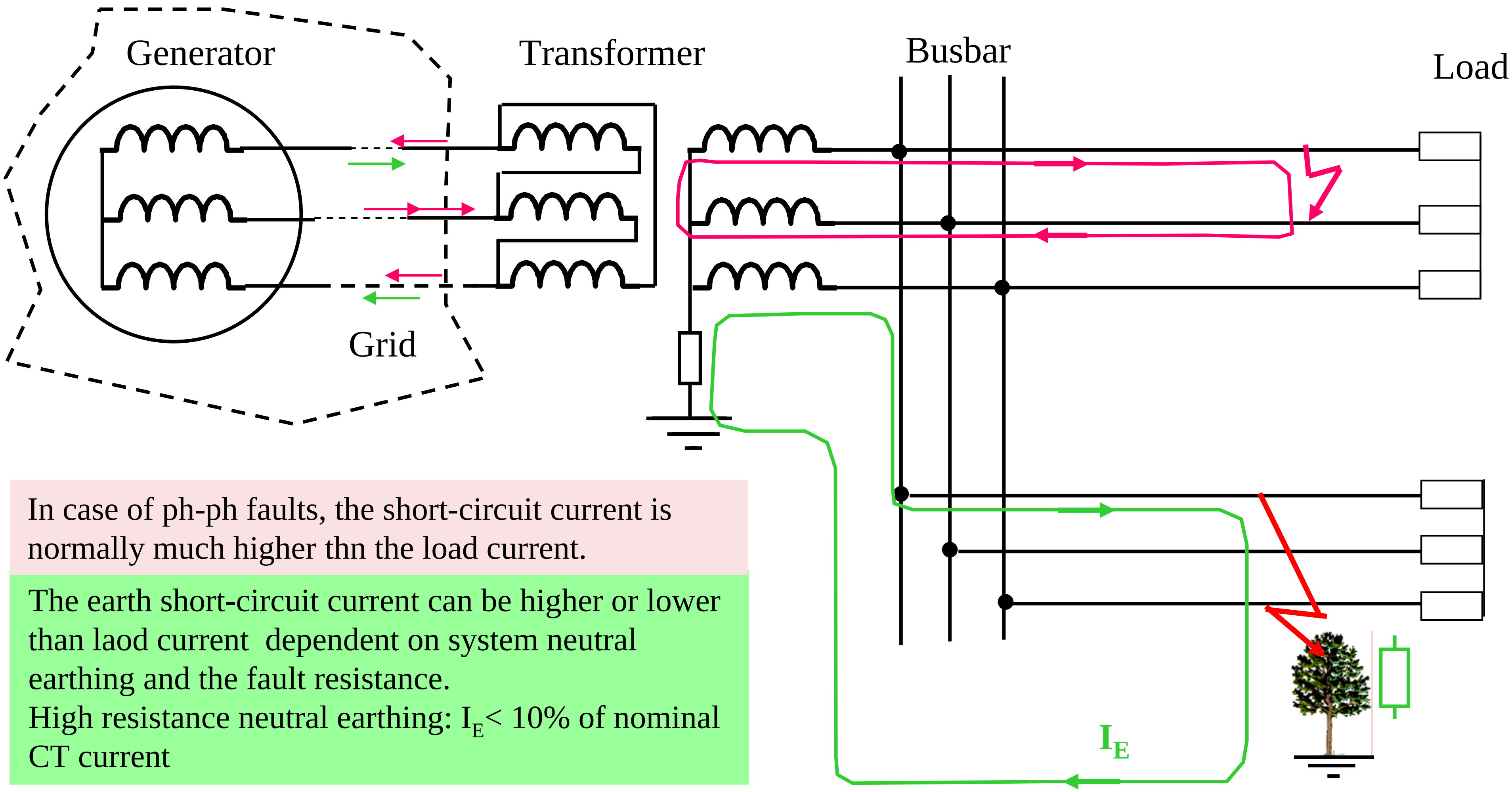
$$Z_S = \frac{110kV^2}{5000MVA} = 2{,}4Ohm$$

$$Z_{SC} = 0{,}4[Ohm/km] \times 20(km)$$
$$= 8Ohm$$

$$\underline{I}_{\text{SC-3-ph}} = \frac{70\text{kV}}{(2{,}4 + 8{,}0)\text{Ohm}}$$
$$= 6{,}7\text{kA}$$

- **Short-circuit power of the infeed (source impedance Z_S)**
- **Line impedance to fault location (short-circuit impedance Z_{SC})**
- **Fault resistance (R_F)**
- **Neutral earthing (earth current limitation, e. g. to 2 kA)**

Fault currents: Ph-Ph and Ph-E short-circuit



In case of ph-ph faults, the short-circuit current is normally much higher thn the load current.

The earth short-circuit current can be higher or lower than laod current dependent on system neutral earthing and the fault resistance.
High resistance neutral earthing: I_E< 10% of nominal CT current

Earth fault – System neutral earthing

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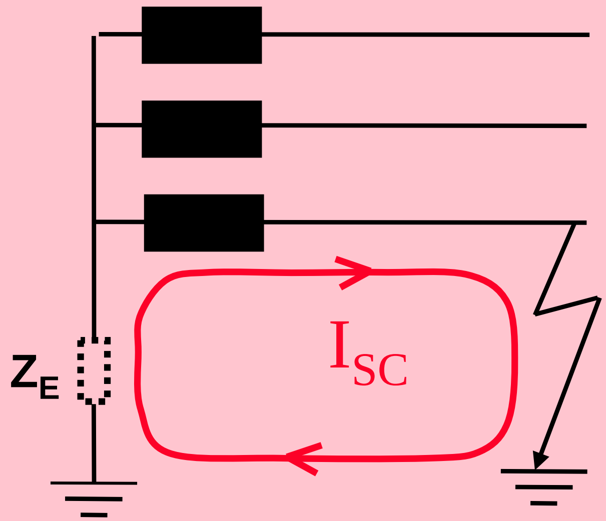
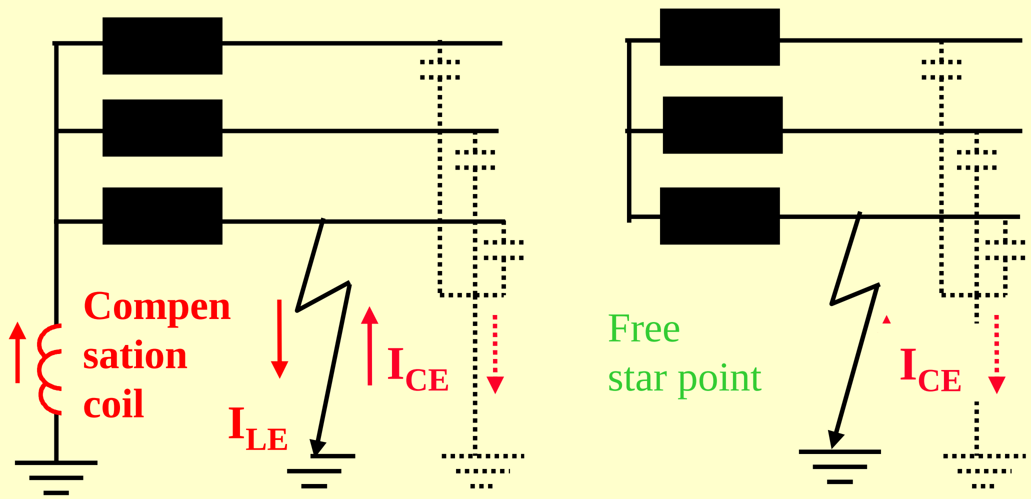


Low impedance (solid) grounding

- Earth fault = **short-circuit**
  Z_E=0: normal over-current protection trips .
- Z_E>0 (I_E < In): Sensitive earth-current step (0.1 to 0.5 x In) required



Compensated **Isolated system**

- Earth fault = **no** short-circuit
- Small current ⇒ service can be continued
- Fault indication by sensitive directional earth fault relays
- Normally no tripping, only alarm
- Manual tripping

Capture of earth-current I_E und and neutral displacement voltage U_E for earth-fault protection

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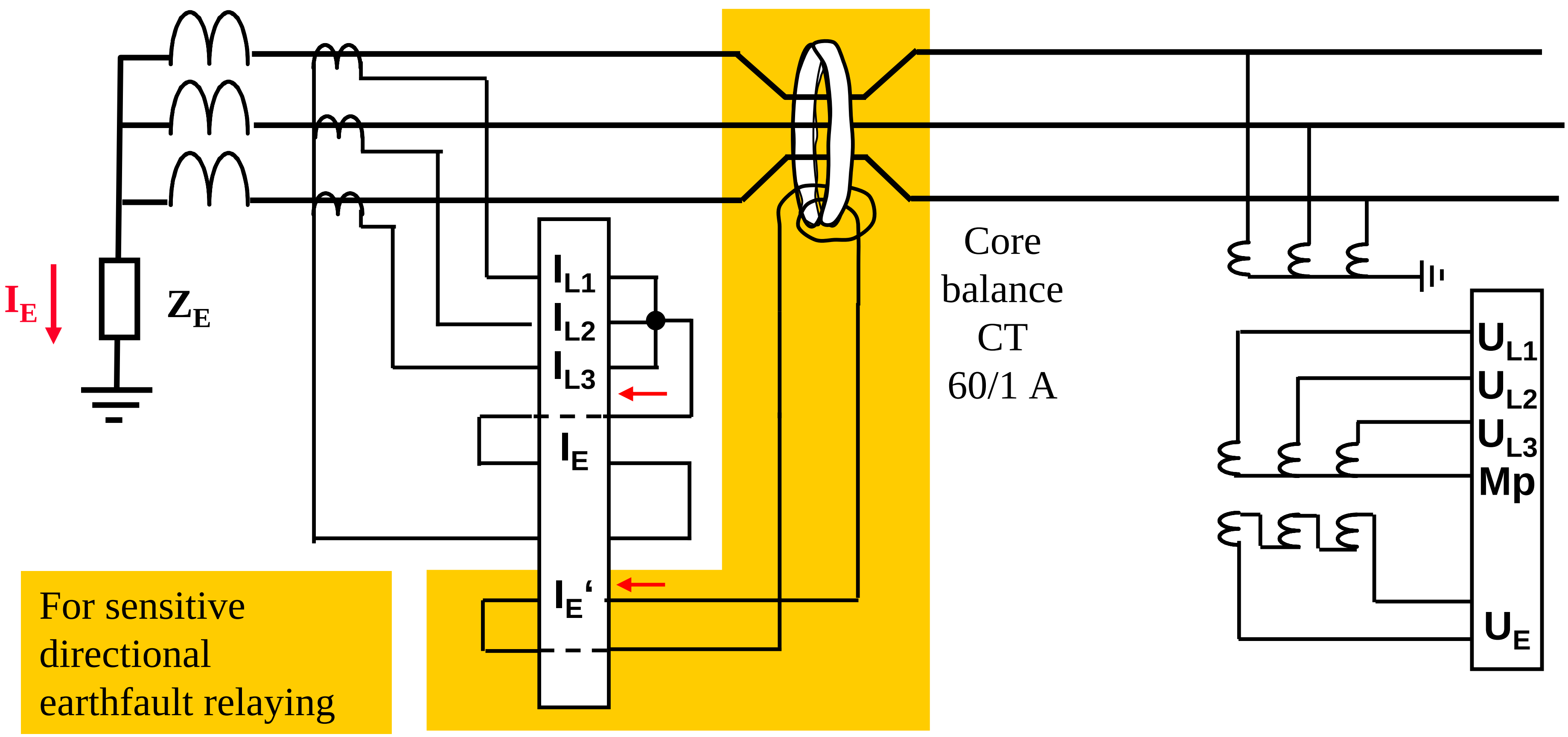


$$I_E = I_{L1} + I_{L2} + I_{L3}$$

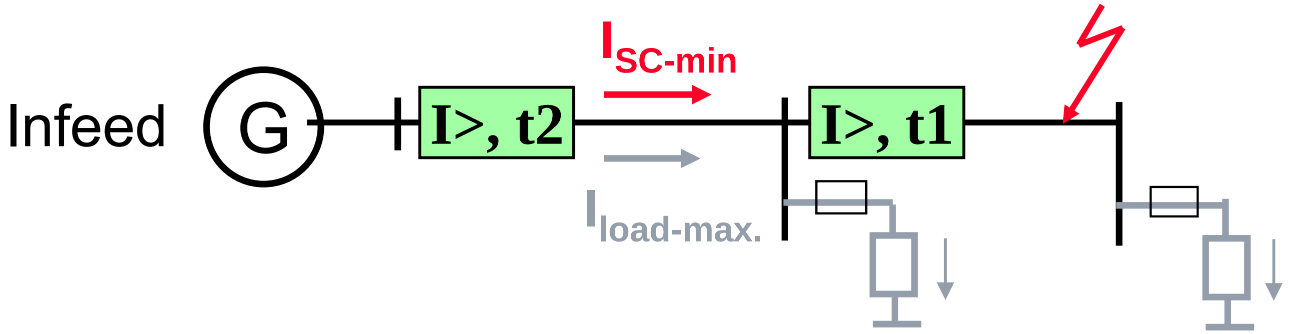
$$U_E = U_{L1} + U_{L2} + U_{L3}$$

Typical Fault criteria

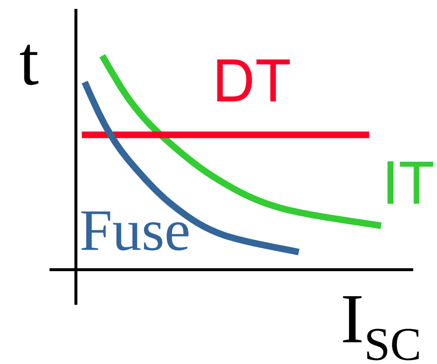
- Overcurrent I>
- Earth-current I_E>
- Undervoltage U<
- Unterimpedanz Z<
- Overvoltage U>
- Leakage (Differential) current ΔI
- Over- and Under-frequency
- Current unbalance (negative sequence current I_2>)
- Special criteria for machine protection

Protection Criterion: “Overcurrent“

Applicable when: $I_{SC\text{-}min} > 2{,}5 \times I_{load\text{-}max.}$



Add-on criterion: Time (t) (to gain selectivity)



Protection methods:

Fuse

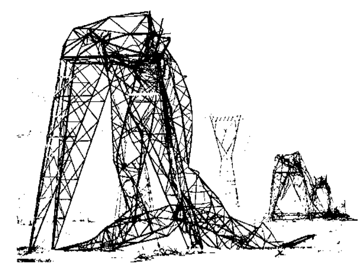
Definite time (DT) over-current relay

Inverse time (IT) overcurrent relay

Typical fault causes

Line faults

Atmospheric impact (lightning, icing, wind)
Growing plants (trees, bush fire)
Mechanical impact (crane, flying objects)
Thermal overload (too large sag of line conductors)



Cable faults

Insulation flash through (for example due to water treeing, water in cable sealings)
Mechanical damage (for example during digging works)
Thermal overload

Power transformer faults and instrument transformer failures

Insulation failure (due to aging, transient overvoltages)
External short-circuits
Thermal overload

Busbar faults

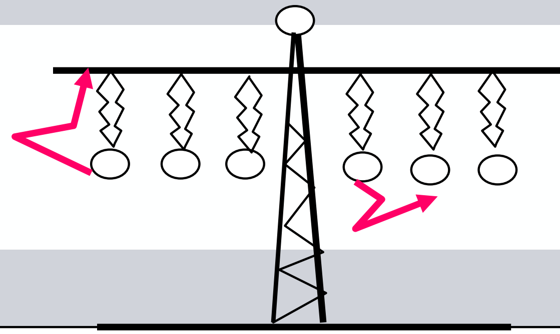
Short-circuits caused by foreign objects (dropping line conductors, animals)
False switching actions (e. g. switching to earth, opening an isolator under load)

Causes of Faults

German Disturbance Statistics, 1986

20 kV:	**110 kV:**	**380kV**	
18042 (13 per 100 km)	2385 (4,9 per 100 km)	357 disturbances (3,4 per 100 km)	
of which:	of which:	of which:	
60 %	31 %	51 %	atmospheric impact
11 %	4 %	4 %	foreign impact
2 %	5 %	8 %	internal reasons
23 %	40 %	11 %	no obvious reason
4 %	20 %	26 %	reaction from other networks

Fault types

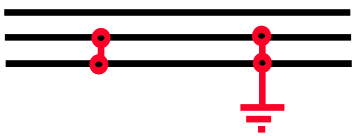


3-phase short-circuit

HV	EHV
5 %	1%

3-phase interruption

2-phase short-circuit



HV	EHV
25 %	6 %

2-phase interruption

1-phase earth short-circuit

HV	EHV
70 %	93 %

1-phase interruption

Requirements on system protection

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  to minimise damage and to ensure system stability

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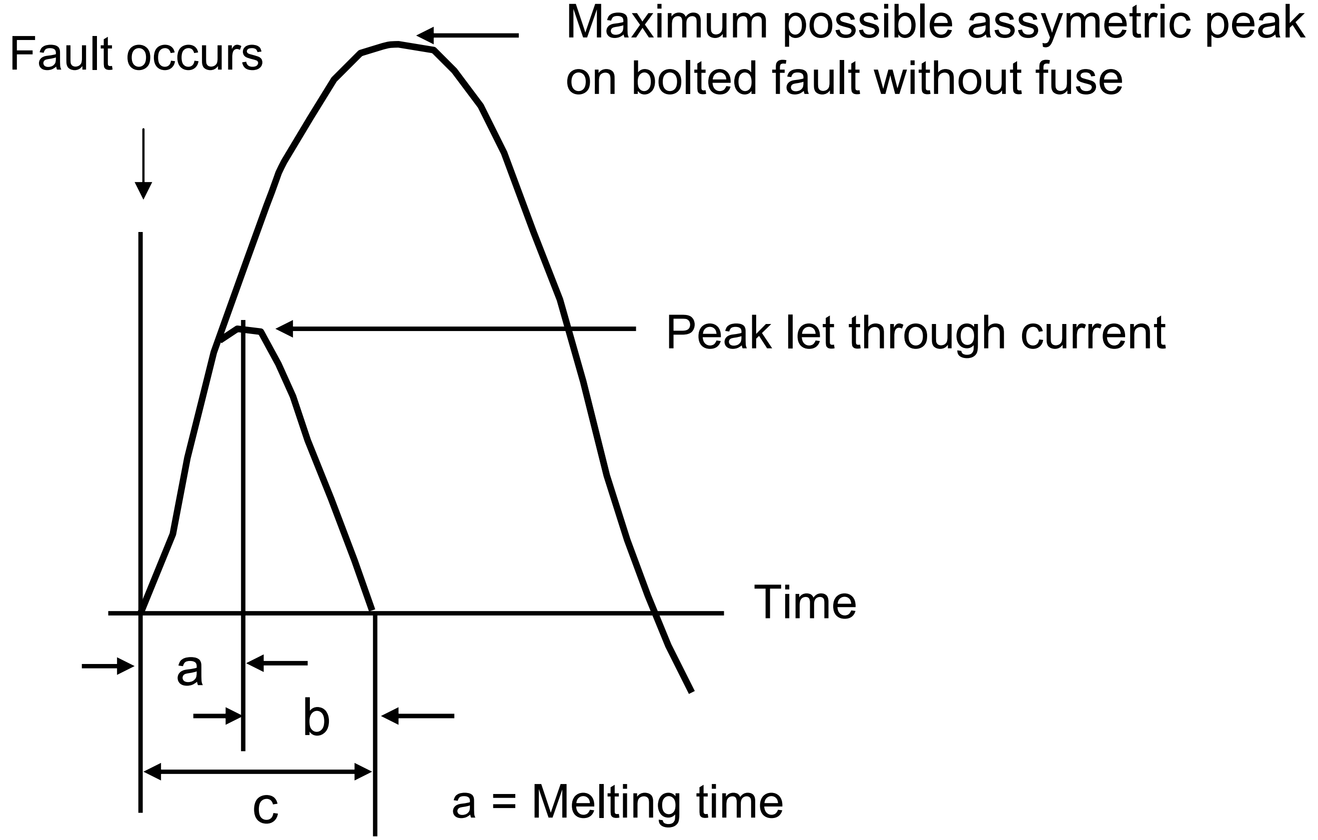
  (high security, no over-function)

Selective means:

- Tripping of only faulty system components,
  leaving the healthy parts in service to continue energy supply

Overcurrent protection,

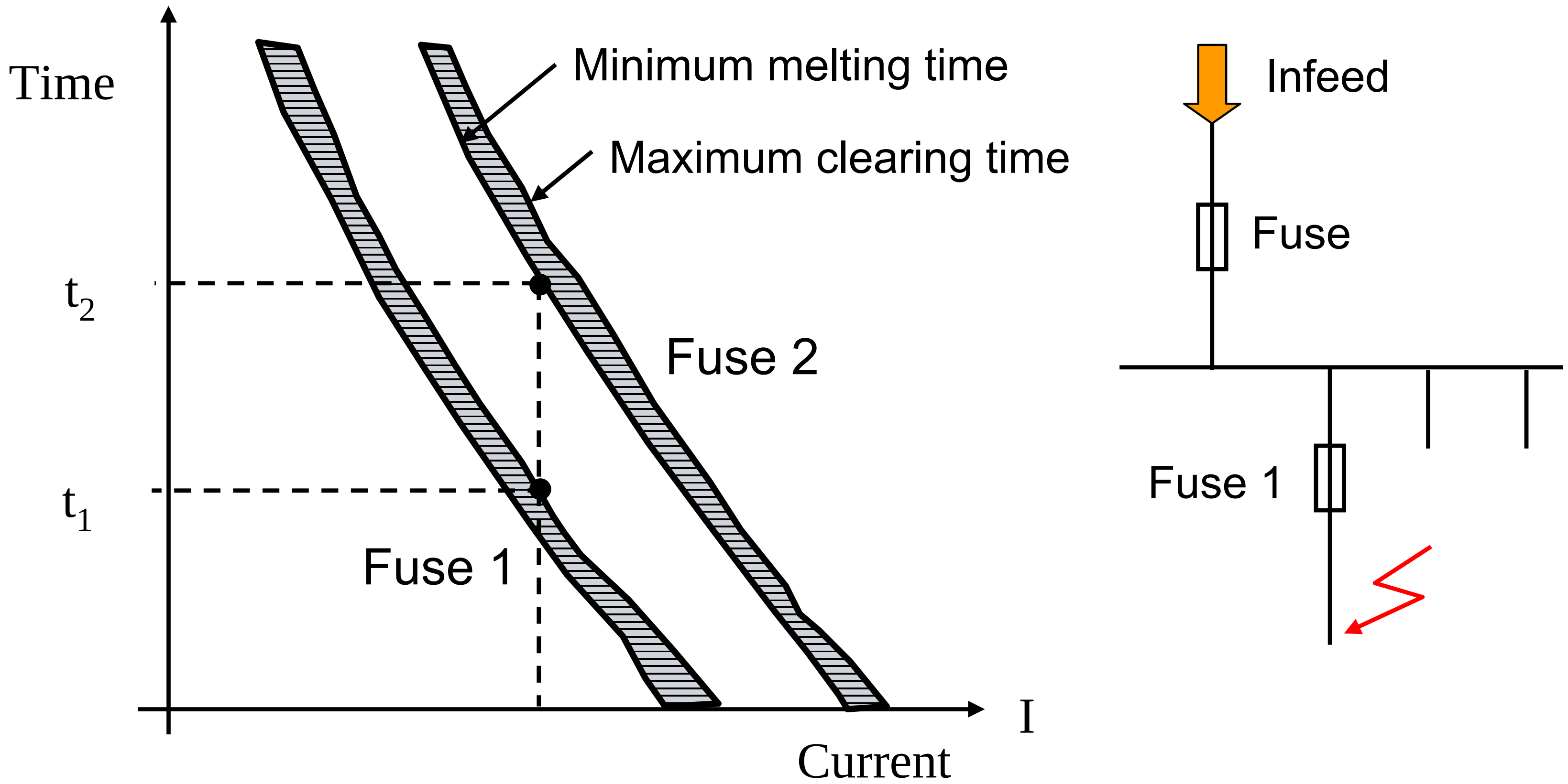
Fuses, Current limitation



a = Melting time
b = arcíng time
c= Total clearing time

Overcurrent protection,

Fuses, Coordination

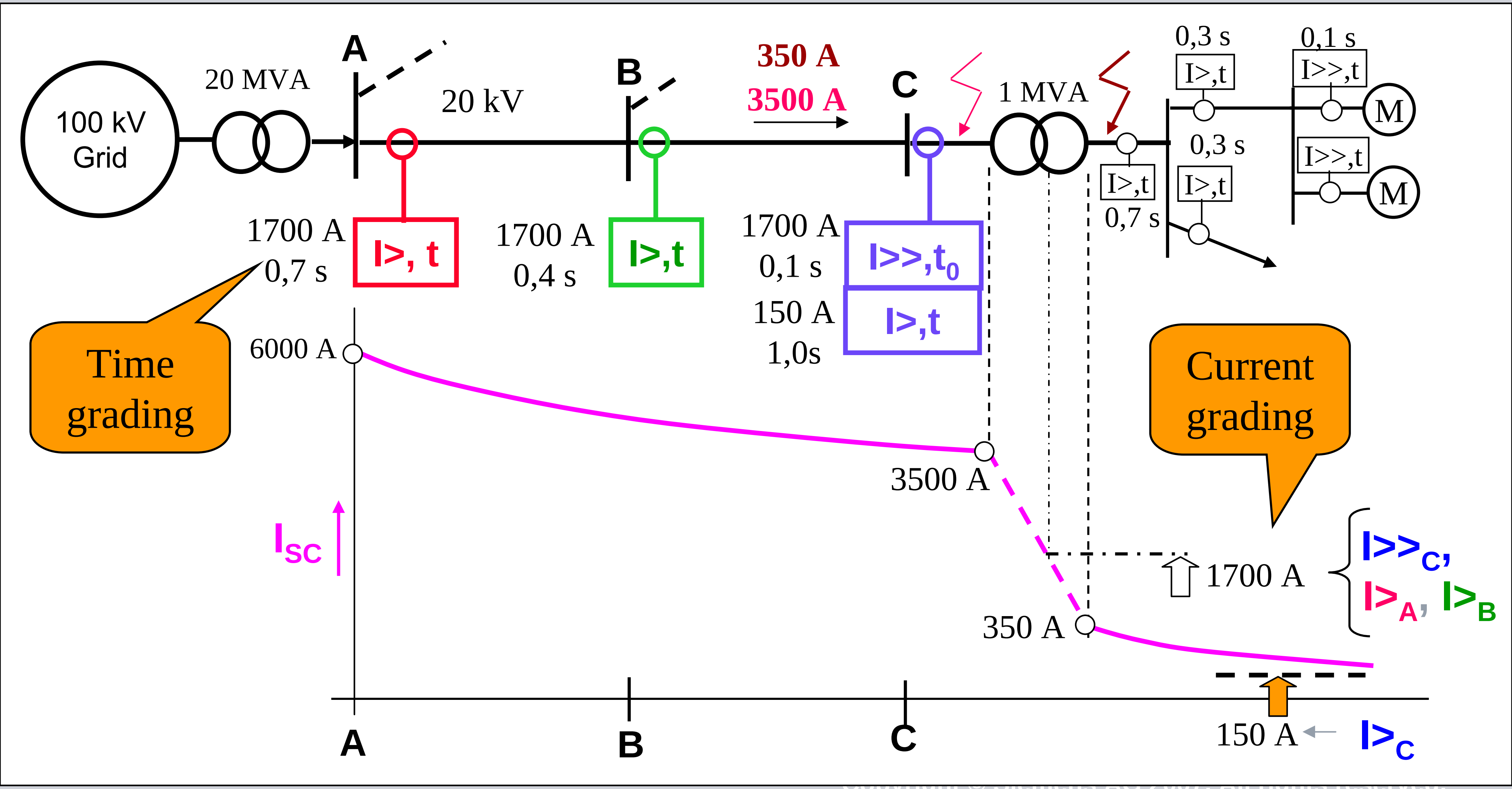


Criteria for fuse-fuse coordination: $t_1 < 0.75\ t_2$

The maximum clearing time of main fuse 1 should not exceed 75% of the minimum melting time of the backup fuse 2.

Overcurrent protection,

Current-Time graded Protection : (Example definite time)



Protection criterium "Impedance"

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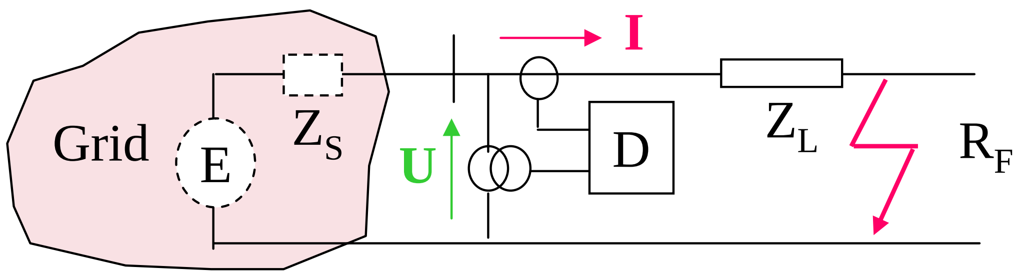
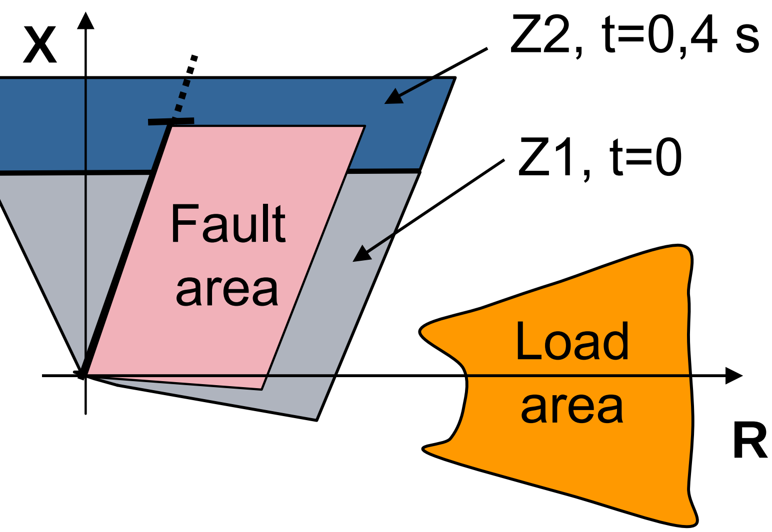
- The relay determines the impedance: $Z = U/I$ from voltage and current at the relay location.



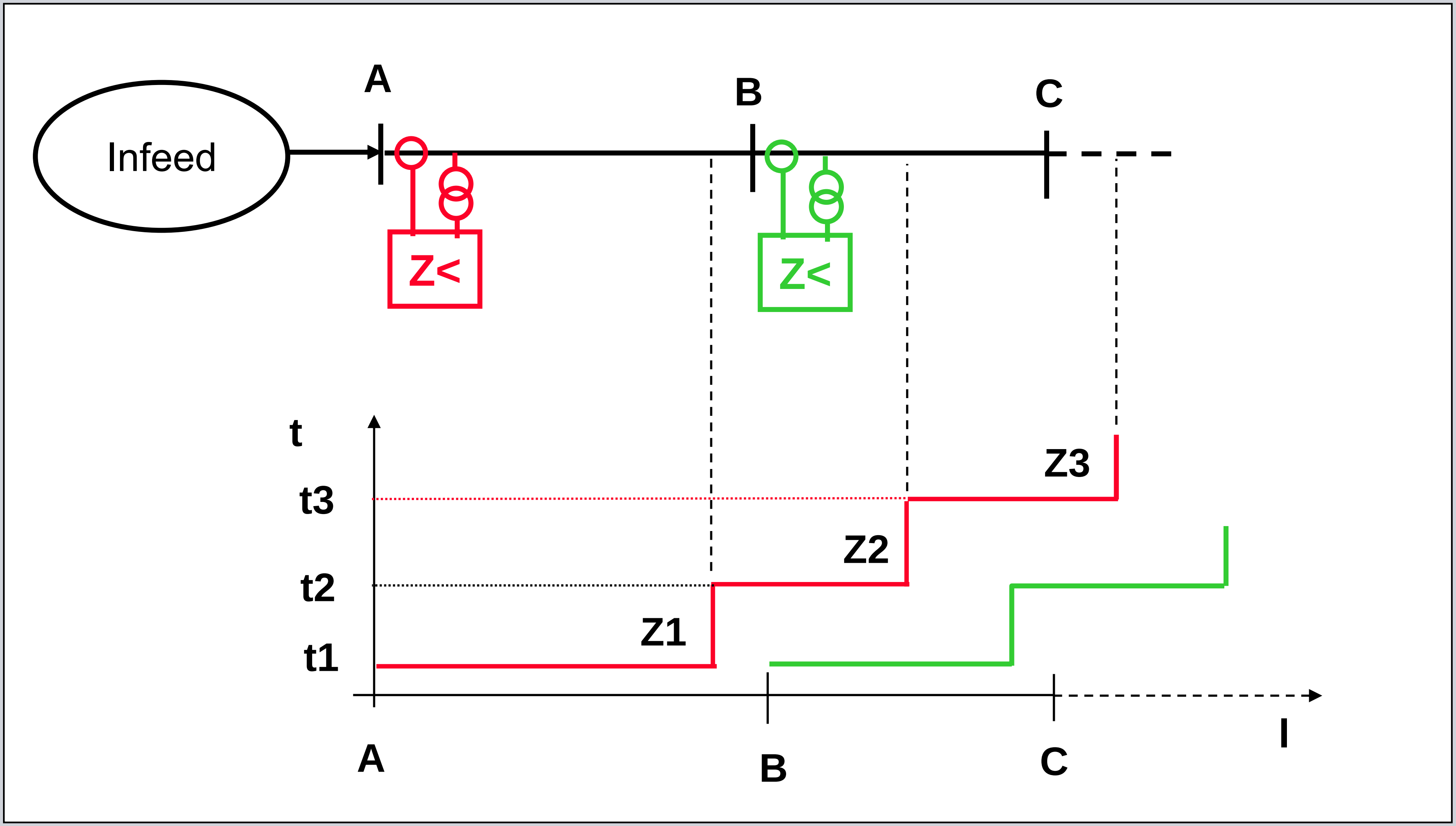
- In the fault case, the measured impedance corresponds to the fault distance

- Time is used as additional criterion (for selectivity and backup)

- Operating characteristic:



Distance protection: Graded zones



Line protection using communication (Signal transmission)
Absolutely selective! Instantaneous fault clearance on 100% line length

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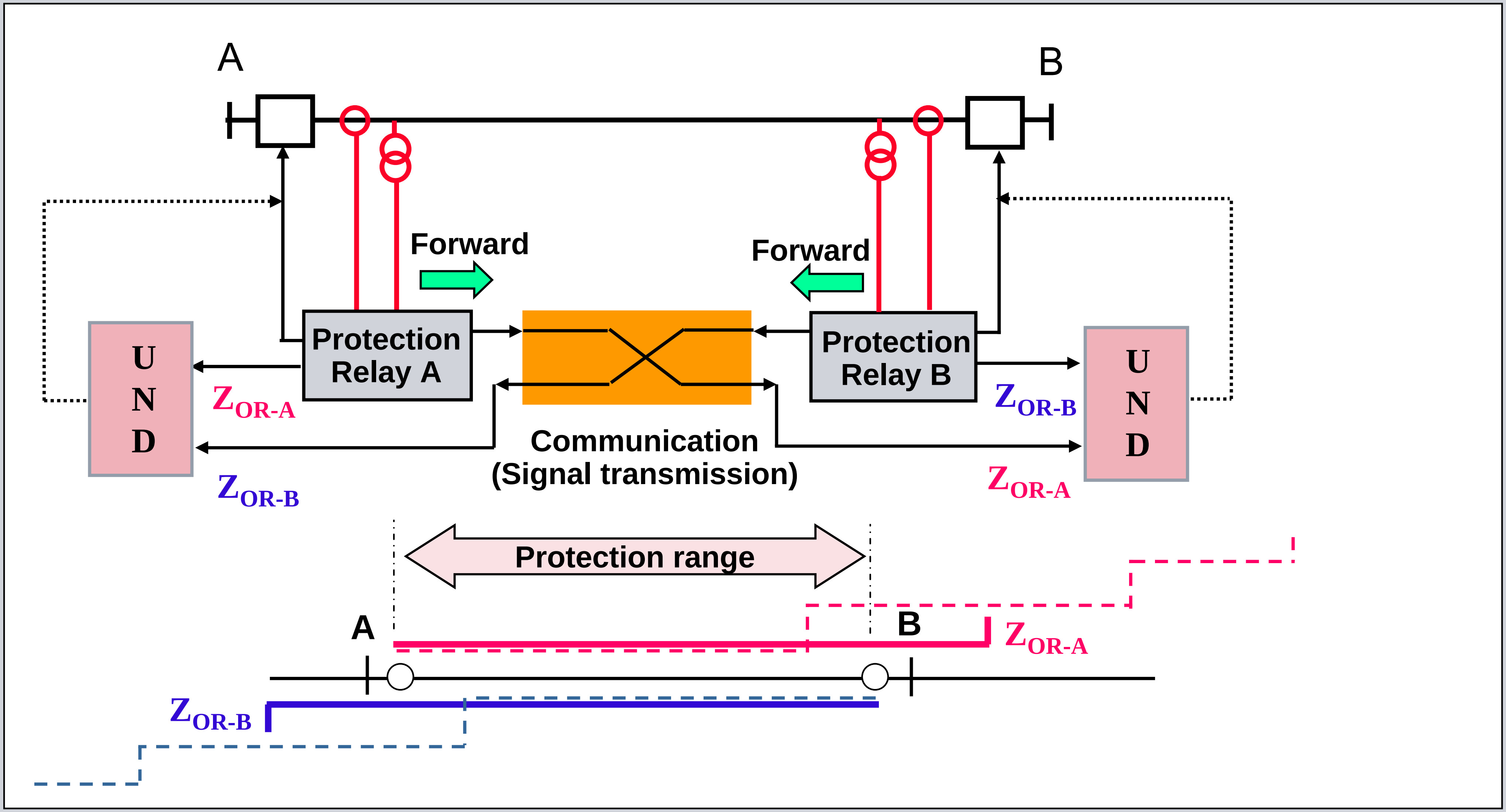

Options for signal transmission

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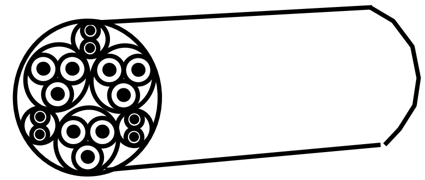
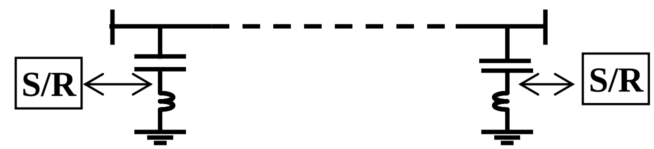
Wire



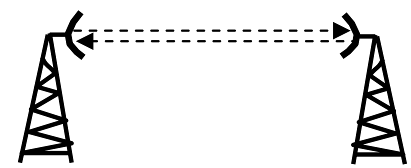
- Short distances up to 20 km (50/60 Hz oder voice frequency),
  (Influence of ground short-circuit currents to be considered)
- Pilot wire differential protection, distance teleprotection, protection command transmission

PLC (Power Line Carrier))



- up to 400 km
- for transmisiion of binary (YES/NO) signals
- distance teleprotection, protection command transmission

Microwave 2 - 10 GHz (digital)



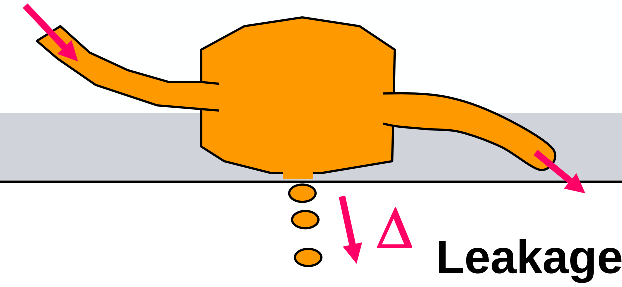
- up to about 50 km (Sight connection)
- Digital communication (n times 64 kbit/s), Line differential protection,
  Digital line differential protection, Distance teleprotection, protection command transmission

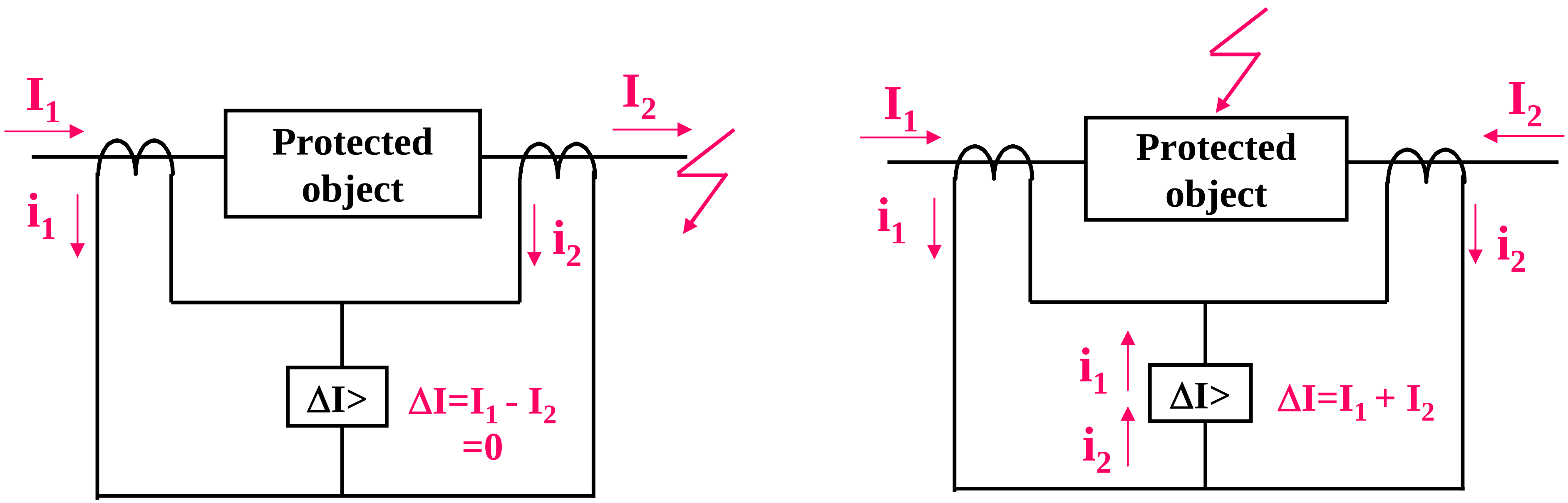
- Optic Fibers

- Digital communication (n times 64 kbit/s), PCM coded data transmission
  Save against electromagnetic interferance,
- Direct relay-to-relay communicatin up to ca 100 km with dedicated fibers
- Communication via data communication networks
-Digital line differential protection, Distance teleprotection, protection command transmission

Principle of "Differential Protection"

Detection of a leakage (current difference)





External fault or load
(Through flowing current)

Internal fault

Stabilised Differential Protection

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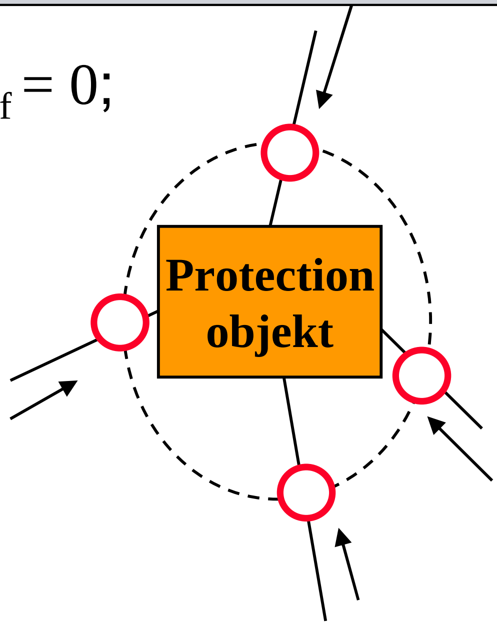
Node criterion (Kirchhoff's law): $\underline{I}_1 + \underline{I}_2 + \underline{I}_3 + \ldots \underline{I}_n = \underline{I}_{diff} = 0;$

$\Sigma \underline{I} \neq 0$ → Fault

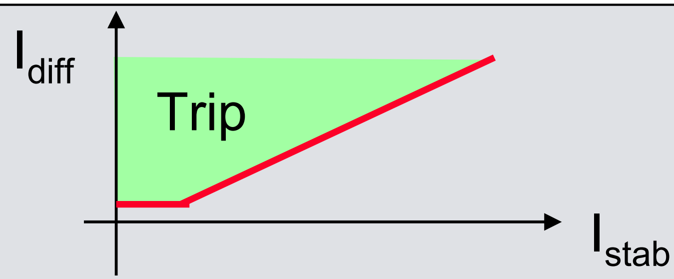
In creased security by current dependent restraint:

$|I1|+|I2|+ \ldots |In| = I_{restraint}$



Operating characteristic:

$I_{opertion} = I_{diff} - k \bullet I_{restraint}$



Advantage: Absolute zone selective (zone borders are CT locations)

Disadvantage: No backup protection for external faults

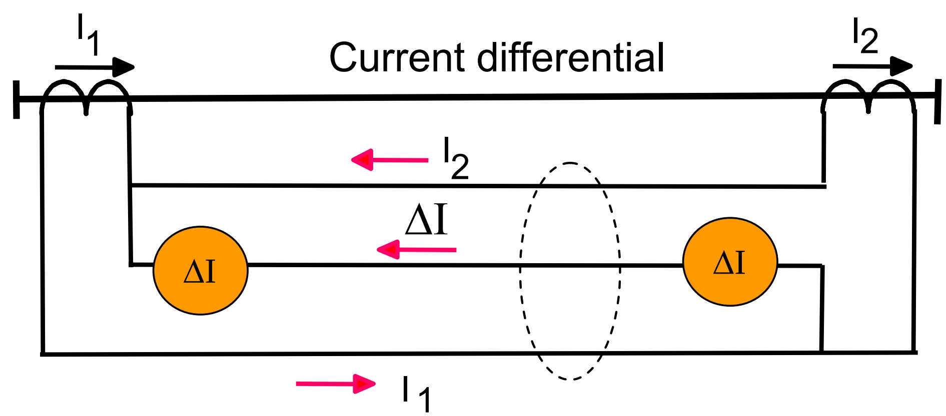
Application:

Differential protection for Generators, Motors, Transformers, Lines/Cables and busbars

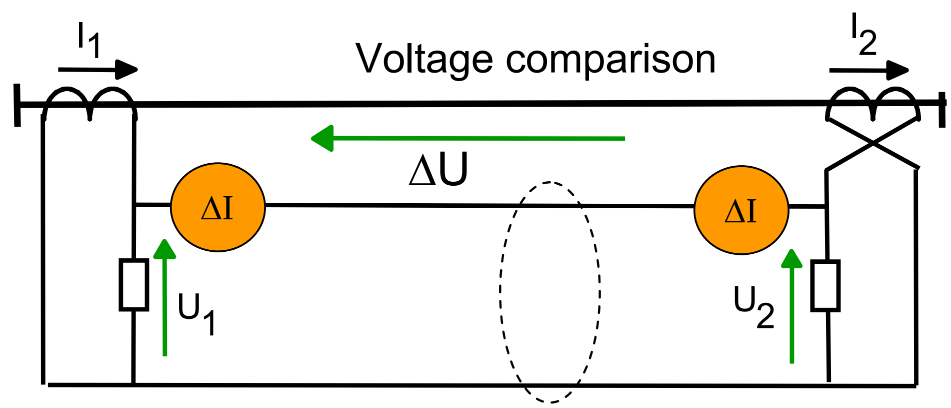
Pilot wire differential protection

Three pilot wires

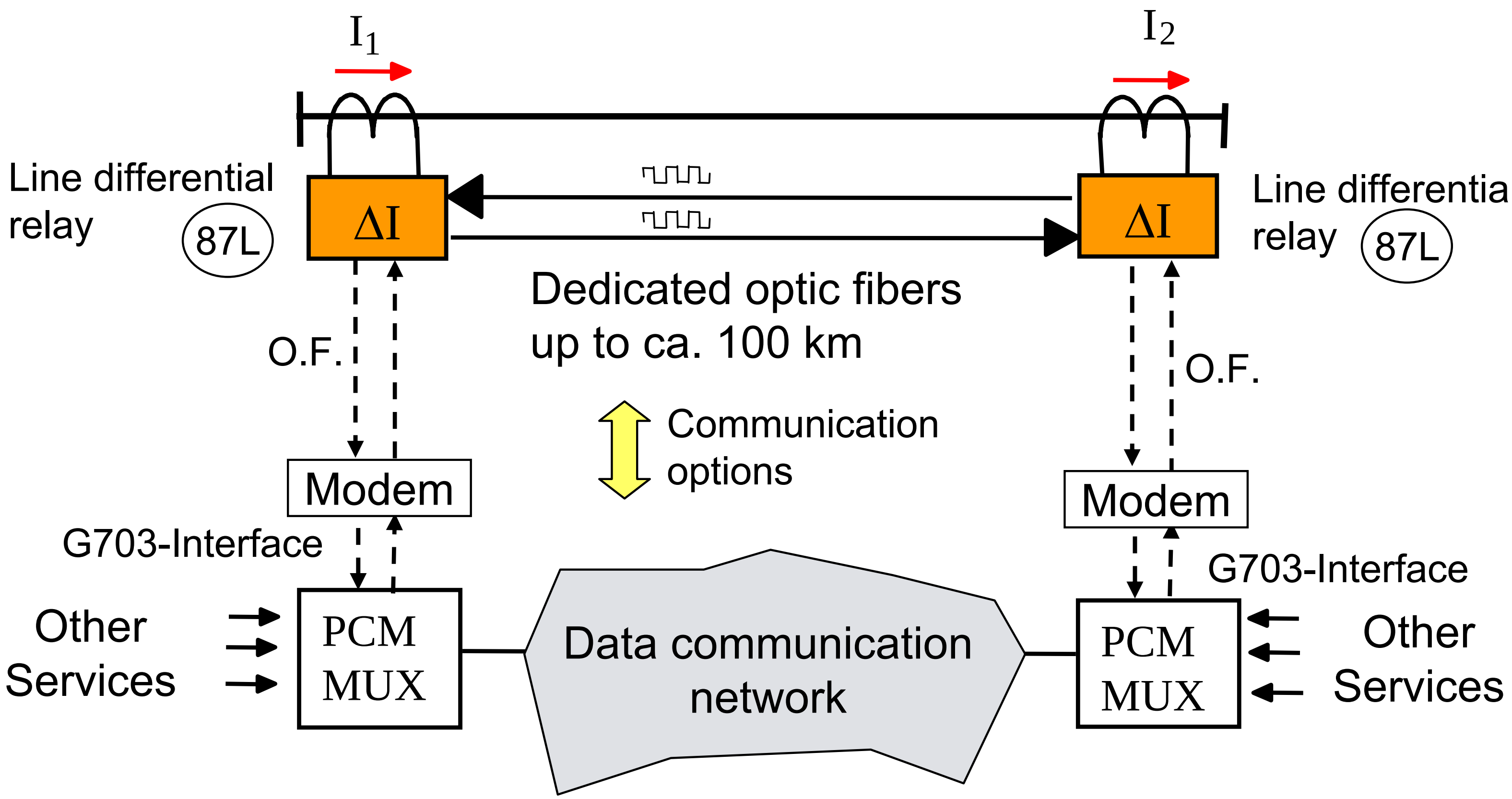
up to ca. 15 km



Two pilot wires
(Twisted pair)
up to ca. 25 km



Digital line differential protection using data communication



Transformer differential protection

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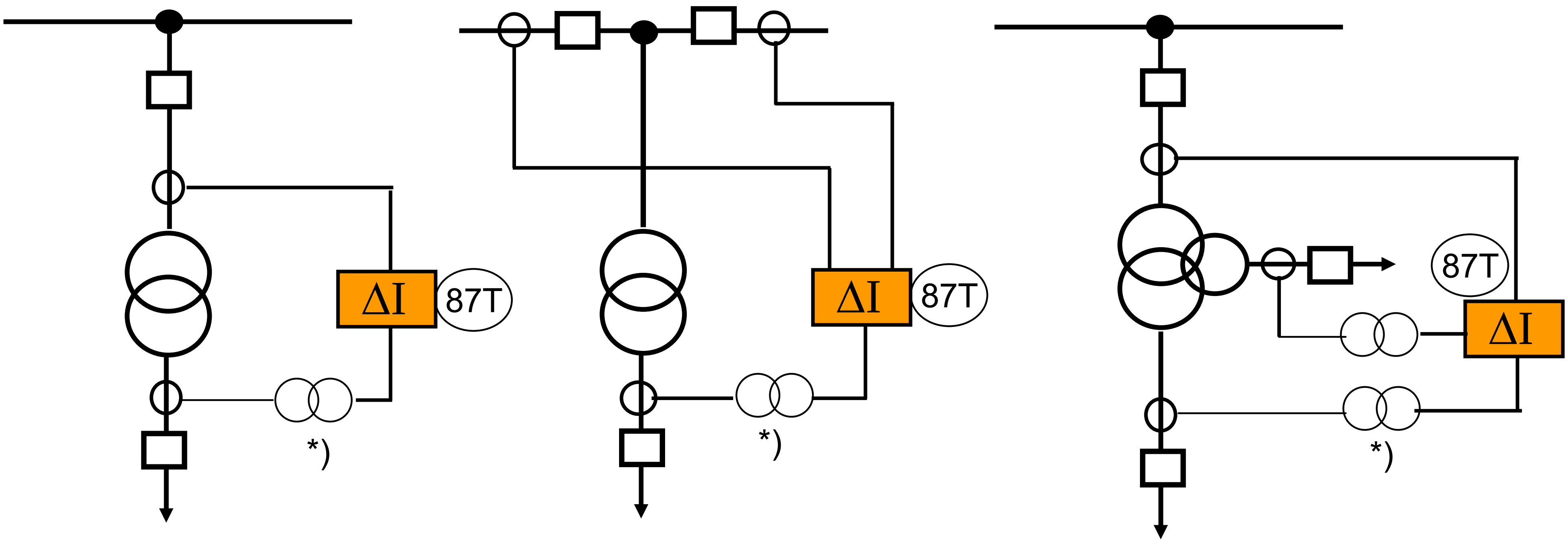


Zweiwickel-
Trafo

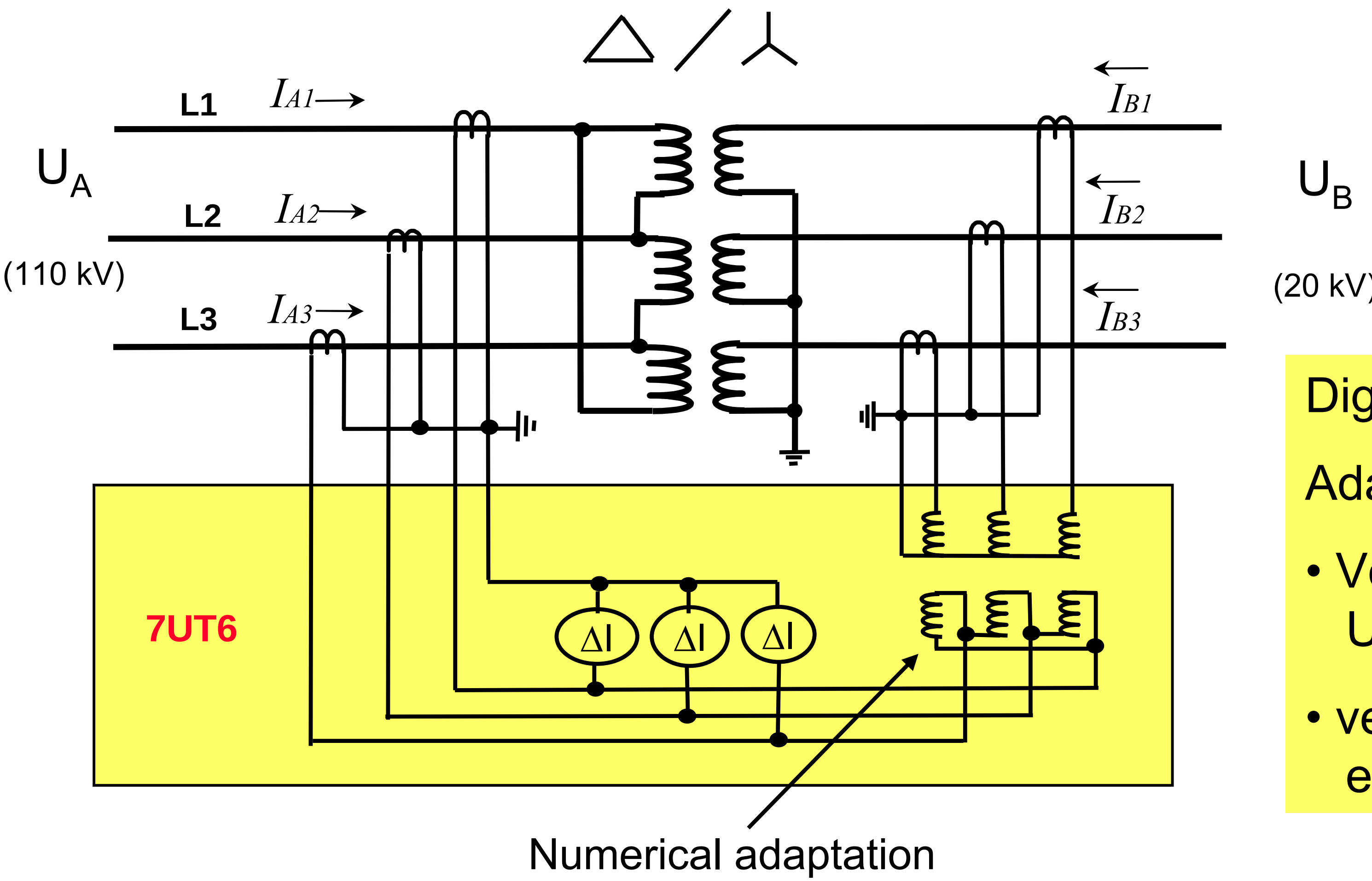
Zweiwickel-Trafo
mit doppelter Einspeisung

Dreiwickel-
Trafo

*) Intermediate CTs for ratio- and vector group adaptation (not necessary with digital relays, as they perform these functions internally by numerical calculation)

Transformer Differential Protection

Three-phase function diagram



Digital relays contain:

Adaptation of

- Voltage ratio(s) U_A / U_B
- vector group(s) e.g. Ynd1

Busbar differential protection

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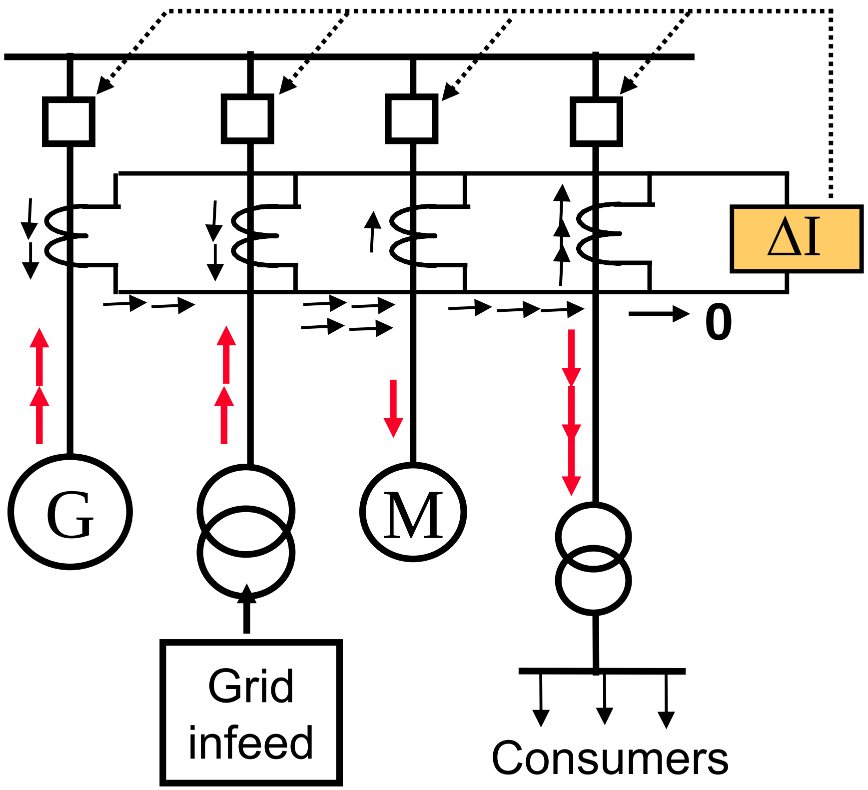
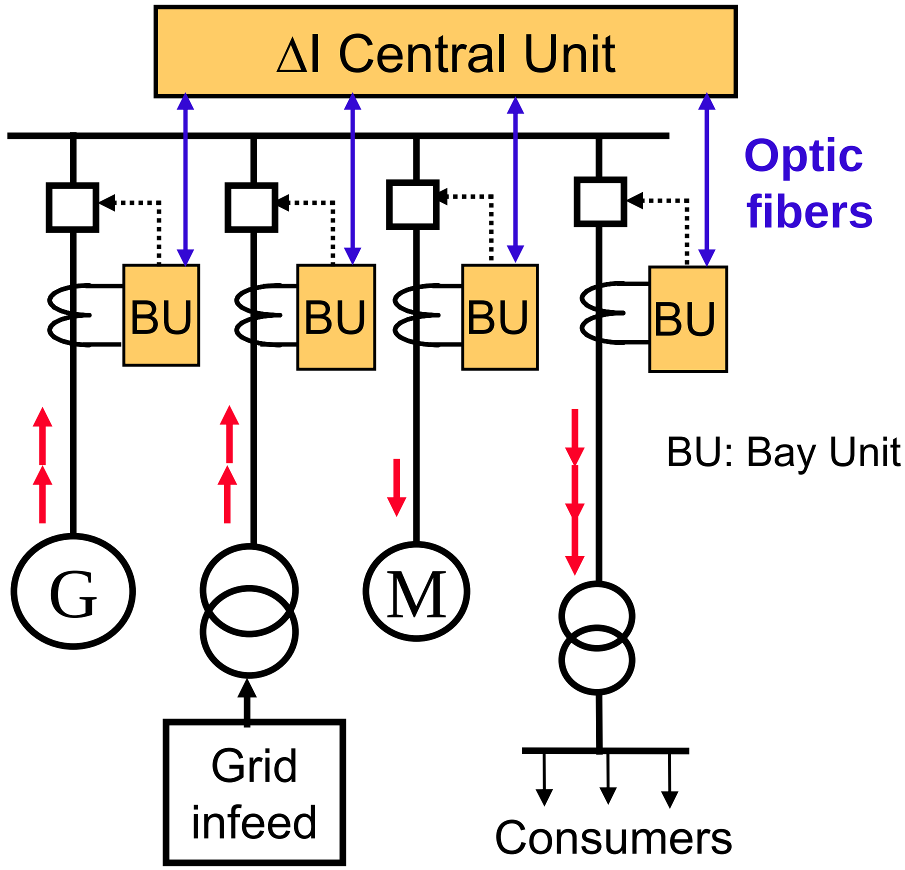
Electromechanical and static relays 7SS10/11/13



Digital Protection 7SS52



Protection of multiple busbar configurations

Double busbar as an example

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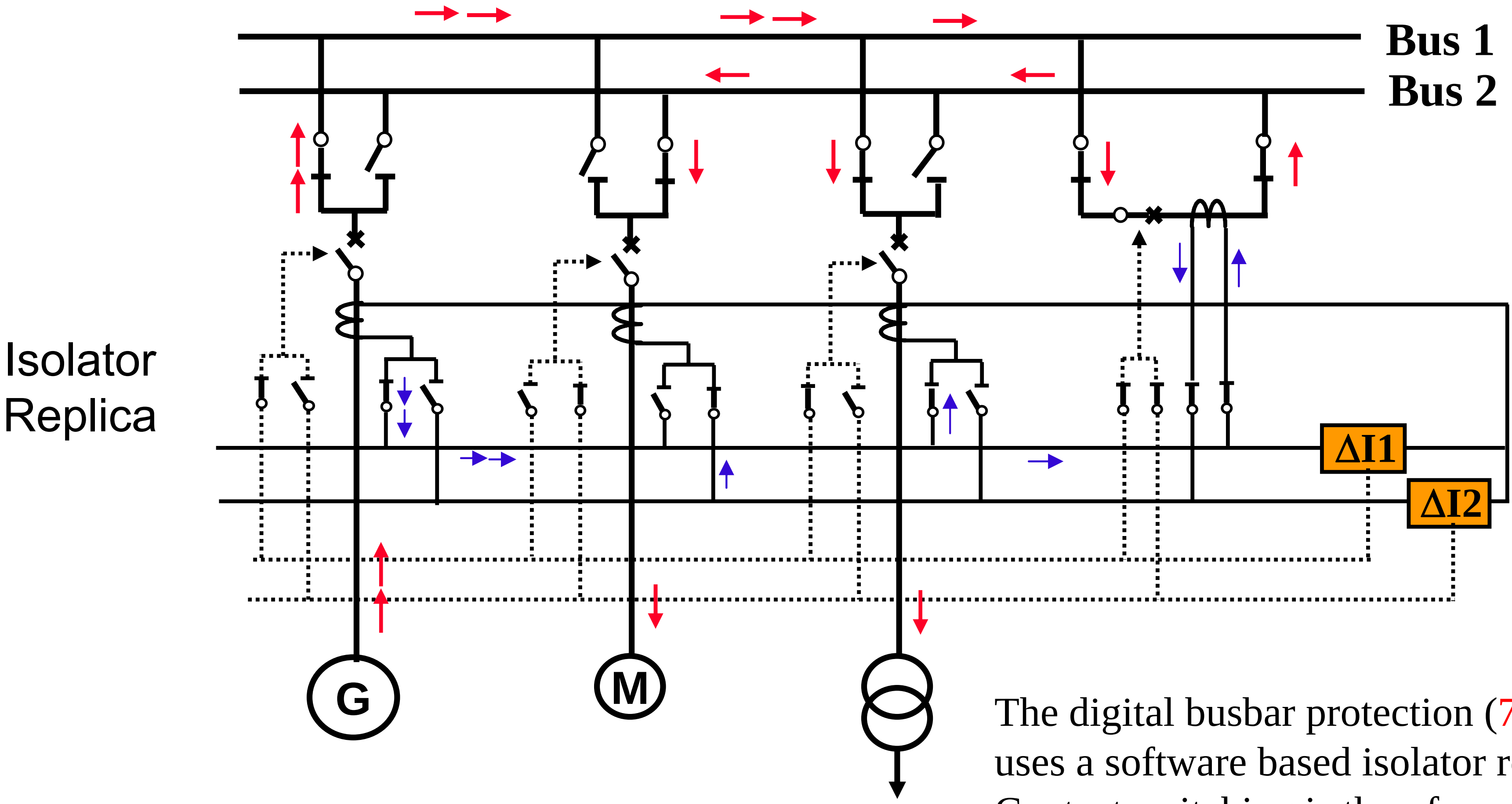

The digital busbar protection (7SS5) uses a software based isolator replica. Contact switching is therefore no more necessary!

High impedance differential protection: Principle

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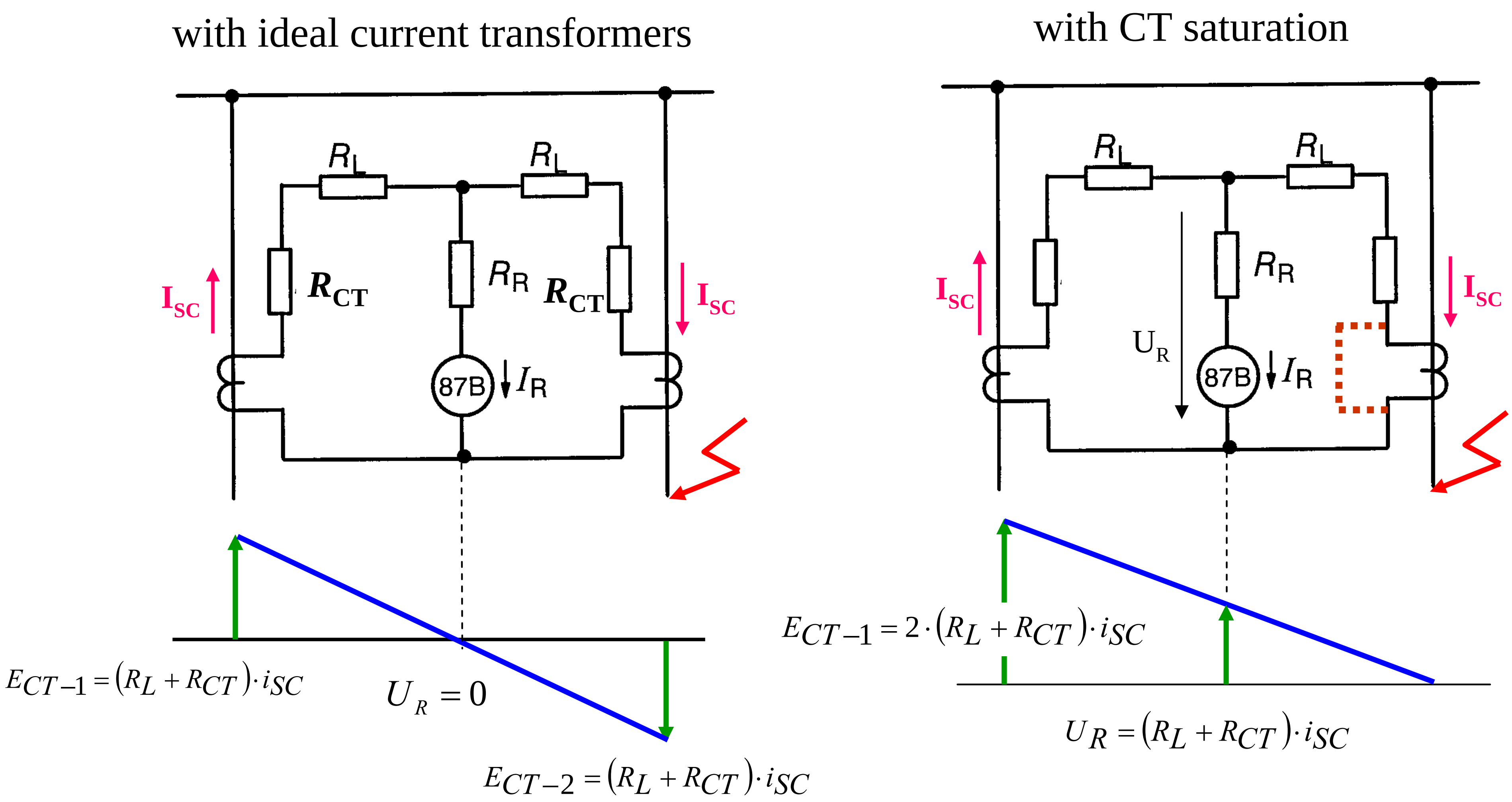
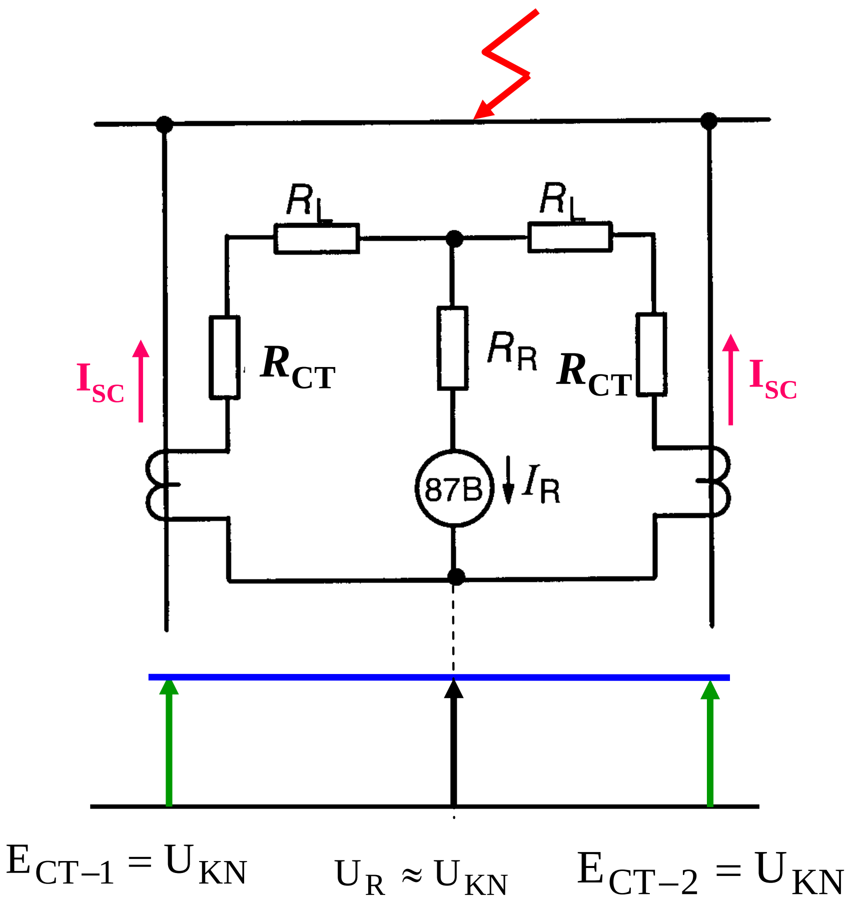
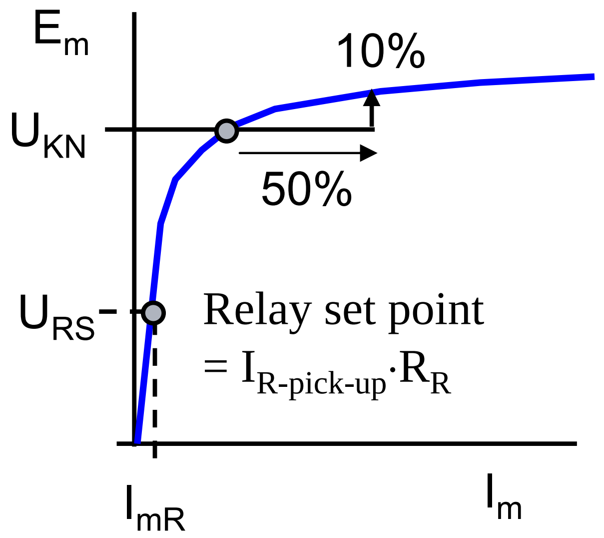
Behaviour during external fault



High impedance differential protection: Principle

Behaviour during internal fault





CT requirement:

$U_{KN} \geq$ 2 times U_{RS}

High impedance differential protection:
Calculation example (busbar protection)

Given: $n = 8$ feeders
$r_{CT} = 600/1$ A
$U_{KN} = 500$ V
$R_{CT} = 4$ Ohm
$I_{mR} = 30$ mA (at relay pick-up value)

$R_L = 3$ Ohm (max.)
$I_{R\text{-pick-up.}} = 20$ mA (fixed value)
$R_R = 10$ kOhm
$I_{var} = 50$ mA (at relay pick-up value)

Pick-up sensitivity:

$$I_{F-\min} = r_{CT} \cdot \left(I_{R-pick-up} + I_{Var} + n \cdot I_{mR} \right)$$

$$I_{F-\min} = \frac{600}{1} \cdot (0.02 + 0.05 + 8 \cdot 0.03)$$

$$I_{F-\min} = 186A \cdot (31\%)$$

Stability:

$$I_{F-through-\max} < r_{CT} \cdot \frac{R_R}{R_L + R_{SW}} \cdot I_{R-pick-up}$$

$$I_{F-throuh-\max} < \frac{600}{1} \cdot \frac{10{,}000}{3+4} \cdot 0.02$$

$$I_{F-through-\max} < 17kA = 28 \cdot I_n$$

High impedance differential protection:
Application notes

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- HI protection can only be used for a galvanically connected circuit (not for transformer differential protection!)
- Other protection relays cannot be connected in series as the CTs saturate heavily in case of internal faults
- Special CT requirements:
  CTs must all have the same ratio and construction, normally Class PX according to IEC 60044-1 with low secondary resistance and leakage reactance
- A voltage limiting device (varistor) may be necessary because high voltage occurs in case of internal faults
- Preferred Application cases:
  Restricted earth fault protection (winding earth-fault protection)
  Differential protection of single busbars
  Differential protection of motors and generators

Backup protection

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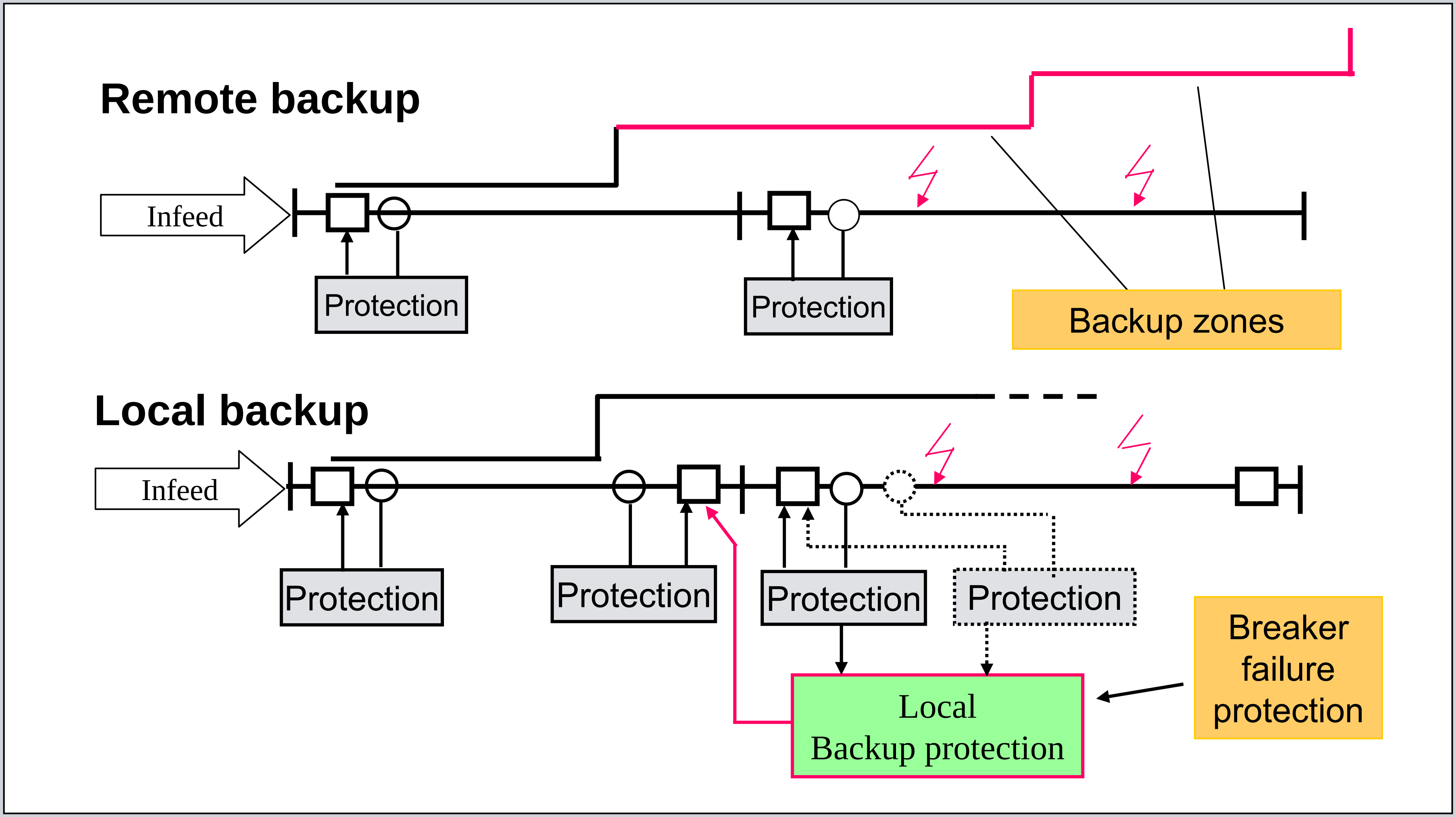
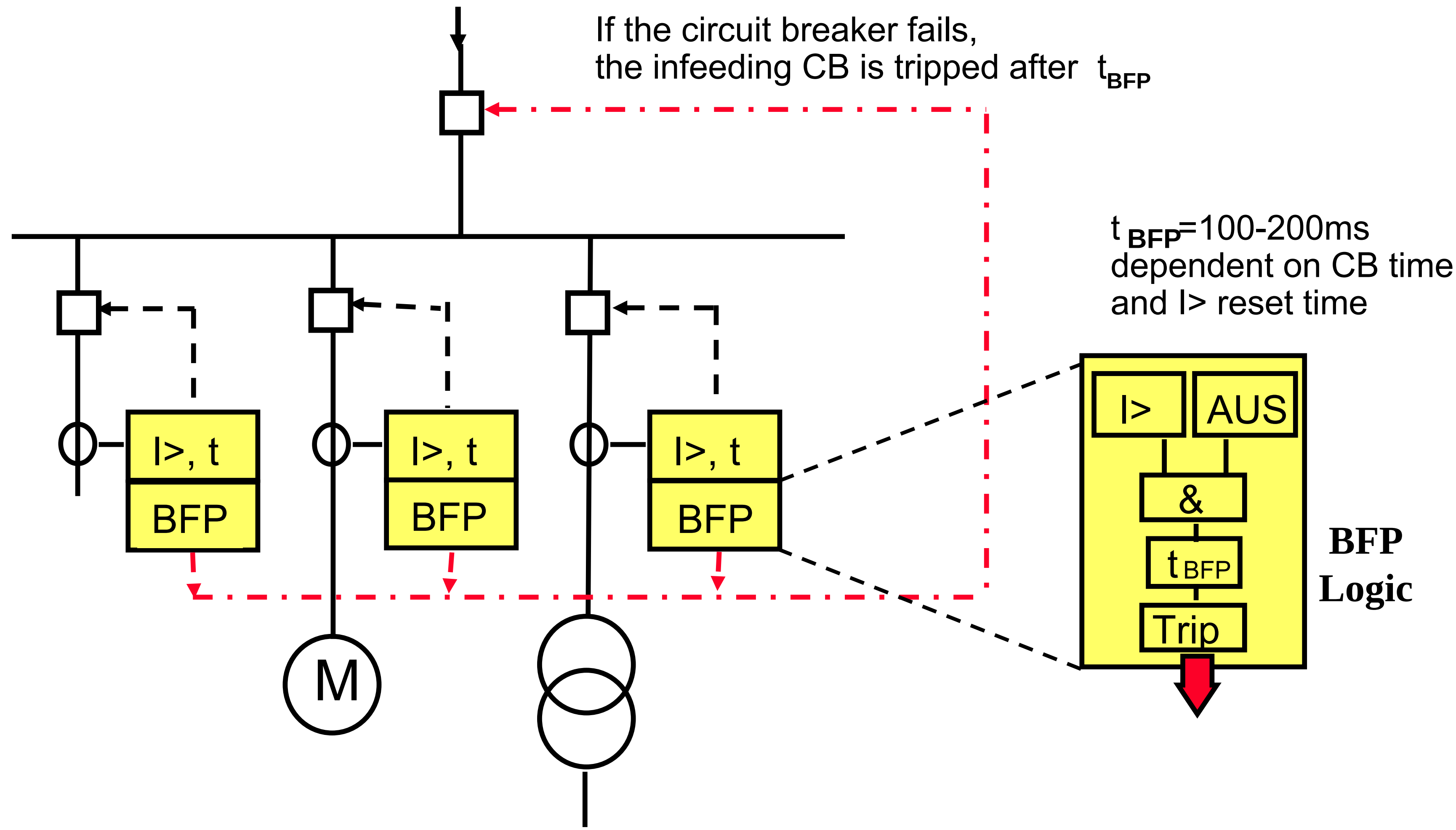
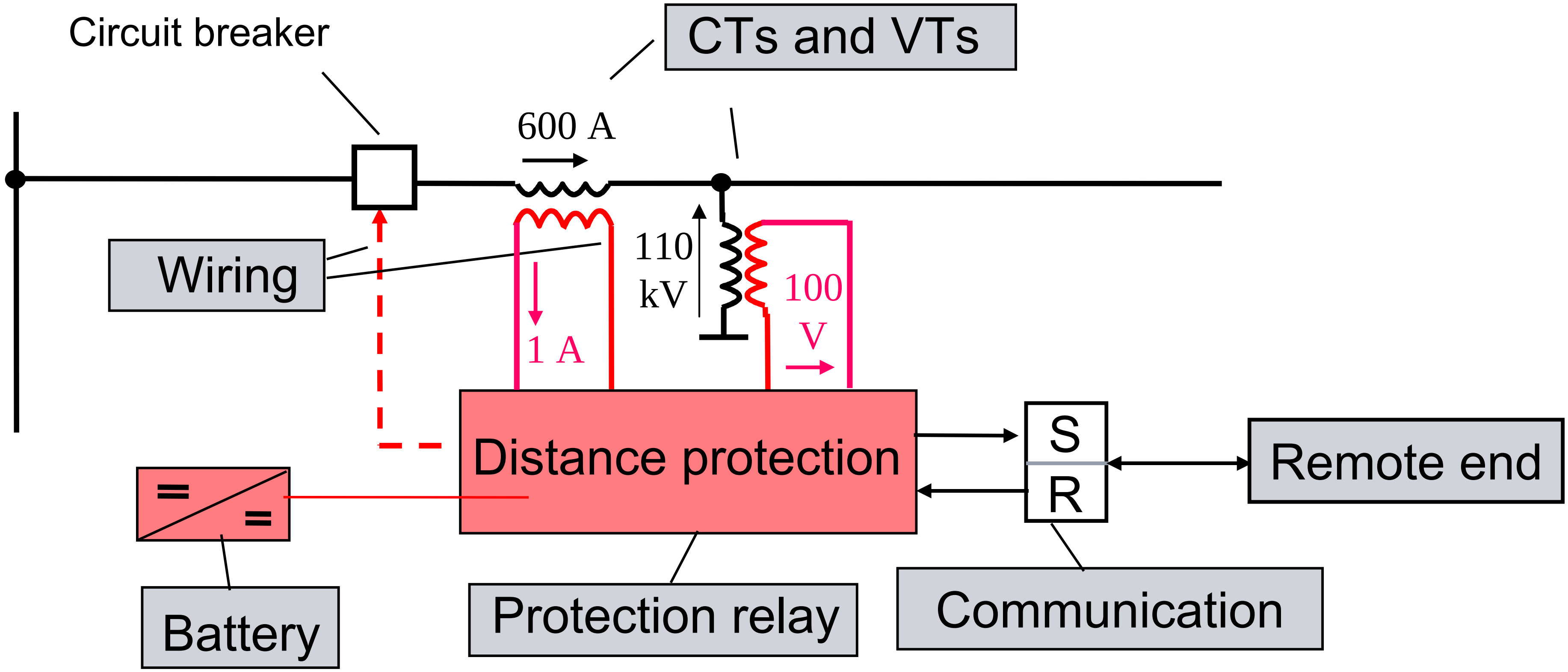


Local backup protection



Protection system



Each system is only as strong as its weakest component !

Current and Voltage transformers

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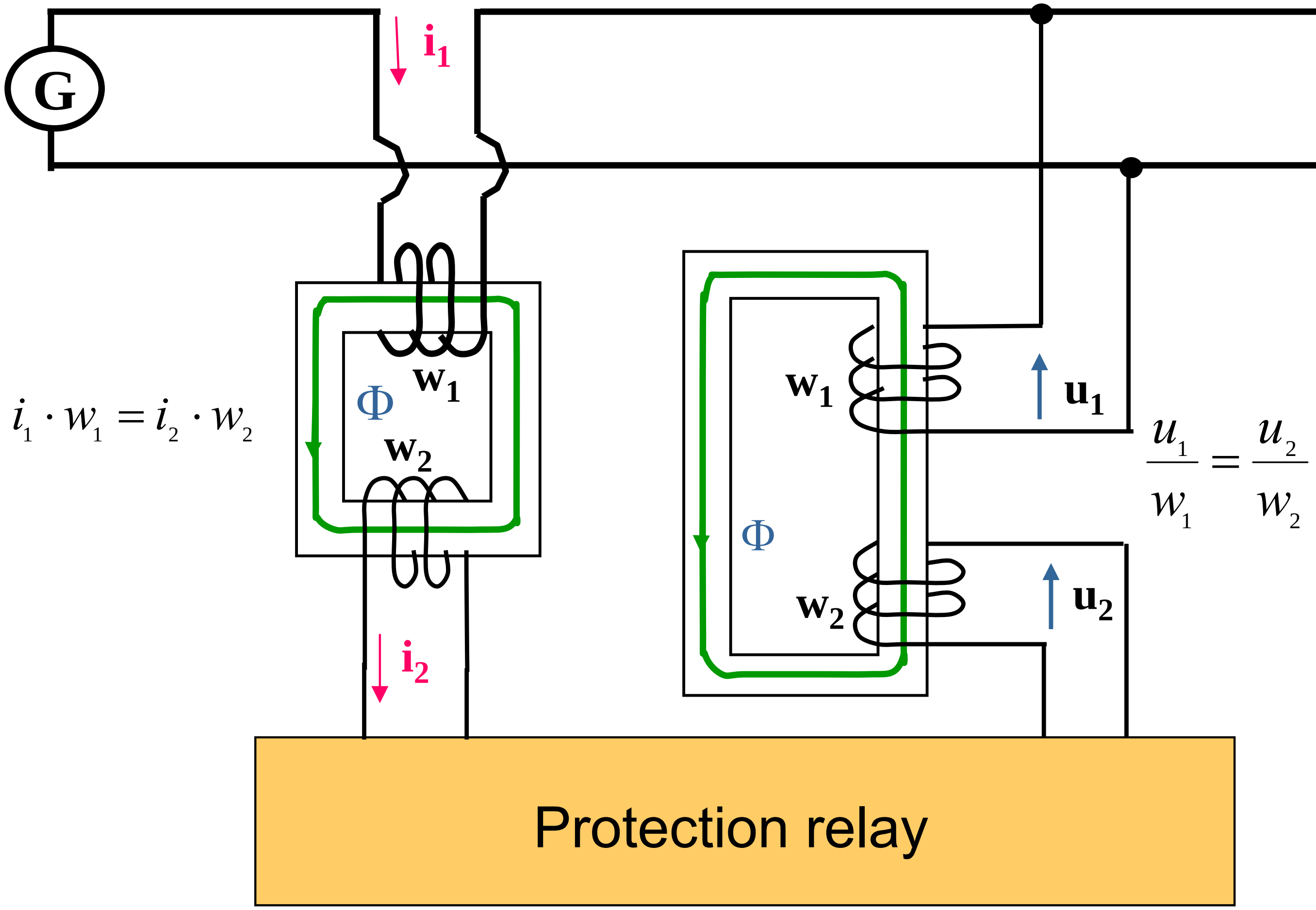
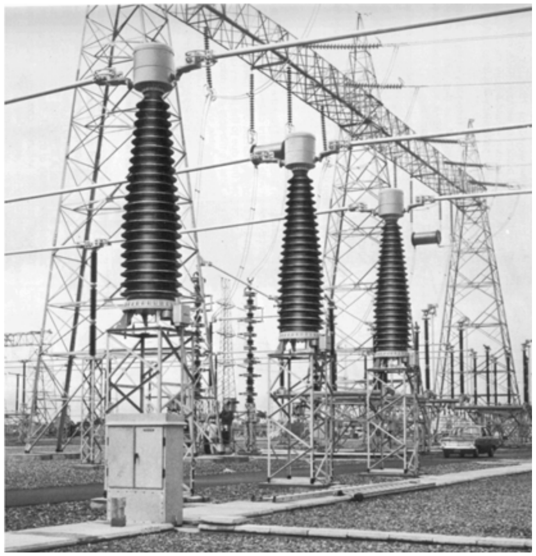


$$i_1 \cdot w_1 = i_2 \cdot w_2$$

$$\frac{u_1}{w_1} = \frac{u_2}{w_2}$$

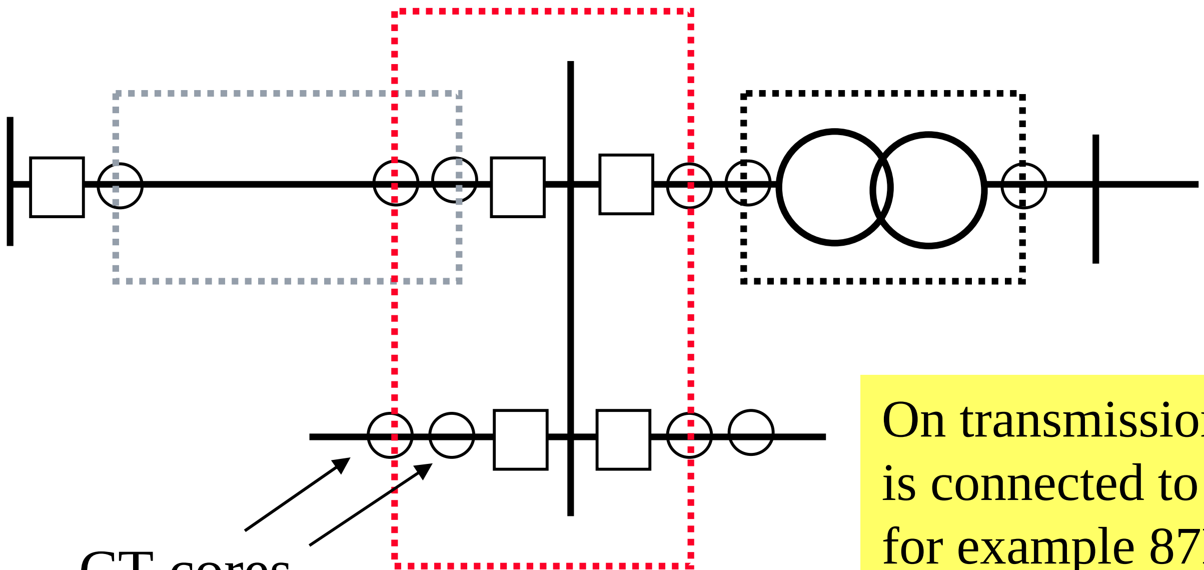


Current transformers for protection

SIEMENS

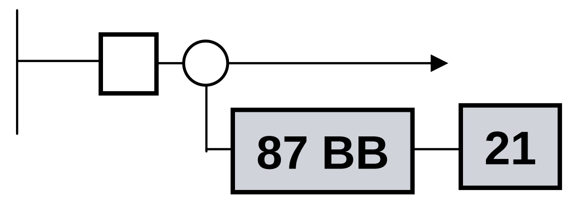
Current transformers

- transform from primary to 1 or 5 A secondary
- define the position of the relay
- define the border of the protection range



CT cores

Relays can be connected in series to the CT cores

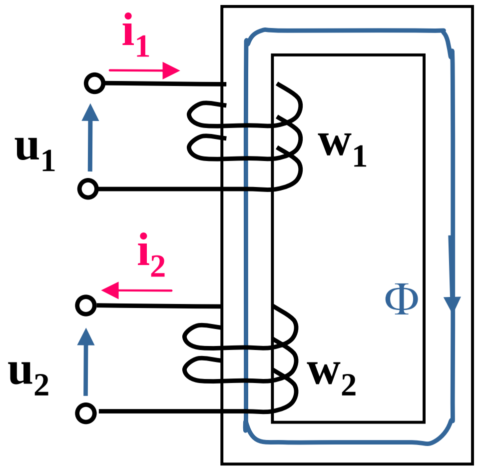


CT burden in operation:

$$P_{OB} = P_{leads} + \sum P_{Relays}$$

On transmission level, each main protection is connected to a separate CT core (redundancy), for example 87BB and 21

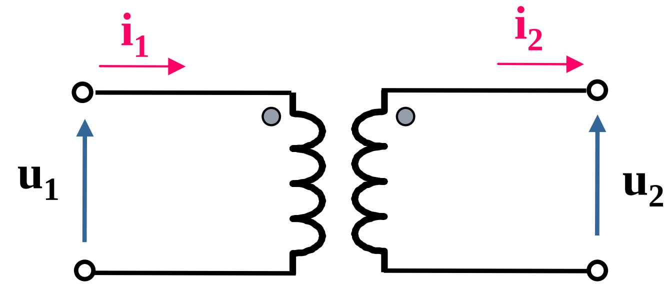
Current transformer:
Principle, transformation ratio, polarity



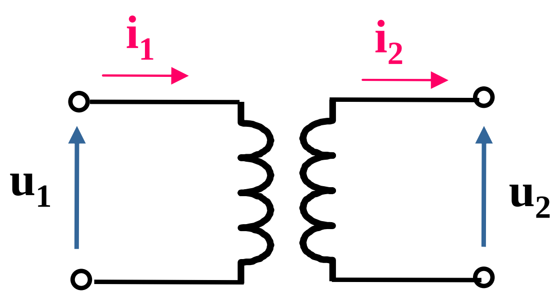
Function principle

① $i_1 \cdot w_1 = i_2 \cdot w_2$

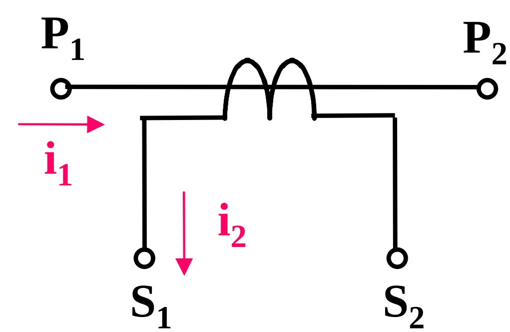
② $\frac{u_1}{w_1} = \frac{u_2}{w_2}$



Polarity marks



Equivalent electrical circuit



Designation of CT terminals
according to IEC 60044-1

Design of protection CTs

SIEMENS

CT standard: IEC 60044-1: 5P oder 10P

$$P_i = I_{sec.}^2 \times R_{CT}$$

CT specification: 300/1 A 5P10, 30 VA $R_{CT} \leq 5$ Ohm

Ratio: $I_{n\text{-prim.}} / I_{n\text{-sec.}}$

Rated power (Rated burden) P_{RB}

5% Accuracy up to I= ALF x In

Accuracy limit factor ALF

The accuracy limit factor in operation depends on the actually connected burden:

Accuracy limit in operation:

$$ALF' = ALF \times \frac{P_i + P_{RB}}{P_i + P_{OB}}$$

Auslegungskriterium:

$$ALF' \geq \frac{I_{SC-max.}}{I_n} \times K_{TF}$$

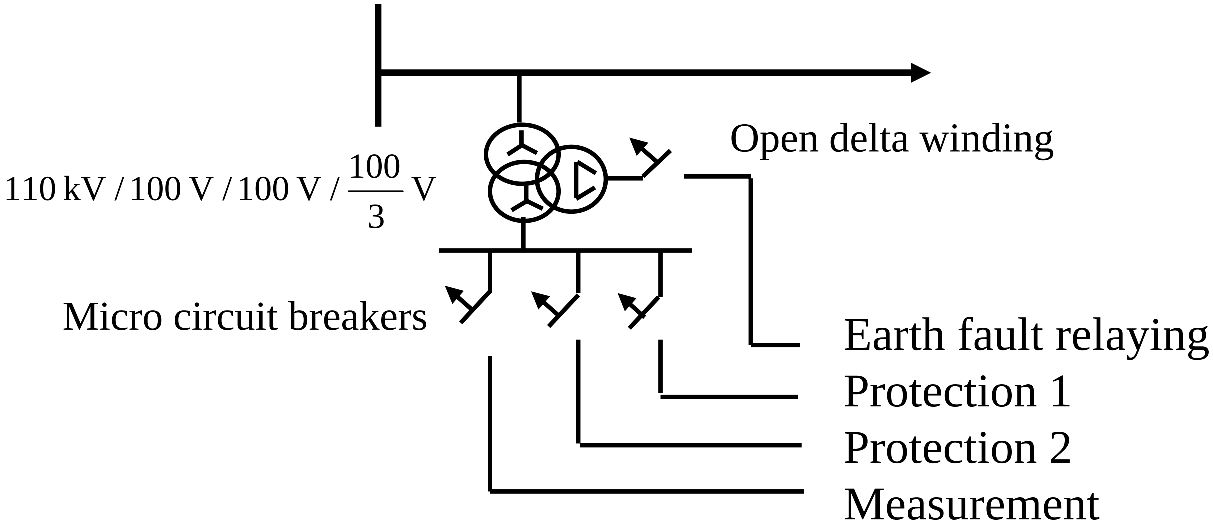
K_{TF} (Transient overdimensioning factor) considers the dc offset of the short-circuit current $I_{SC,}$ (Relay specific requirements, as provided by the manufacturer)

Voltage transformes for protection

SIEMENS

Voltage transformers (VTs) are necessary for

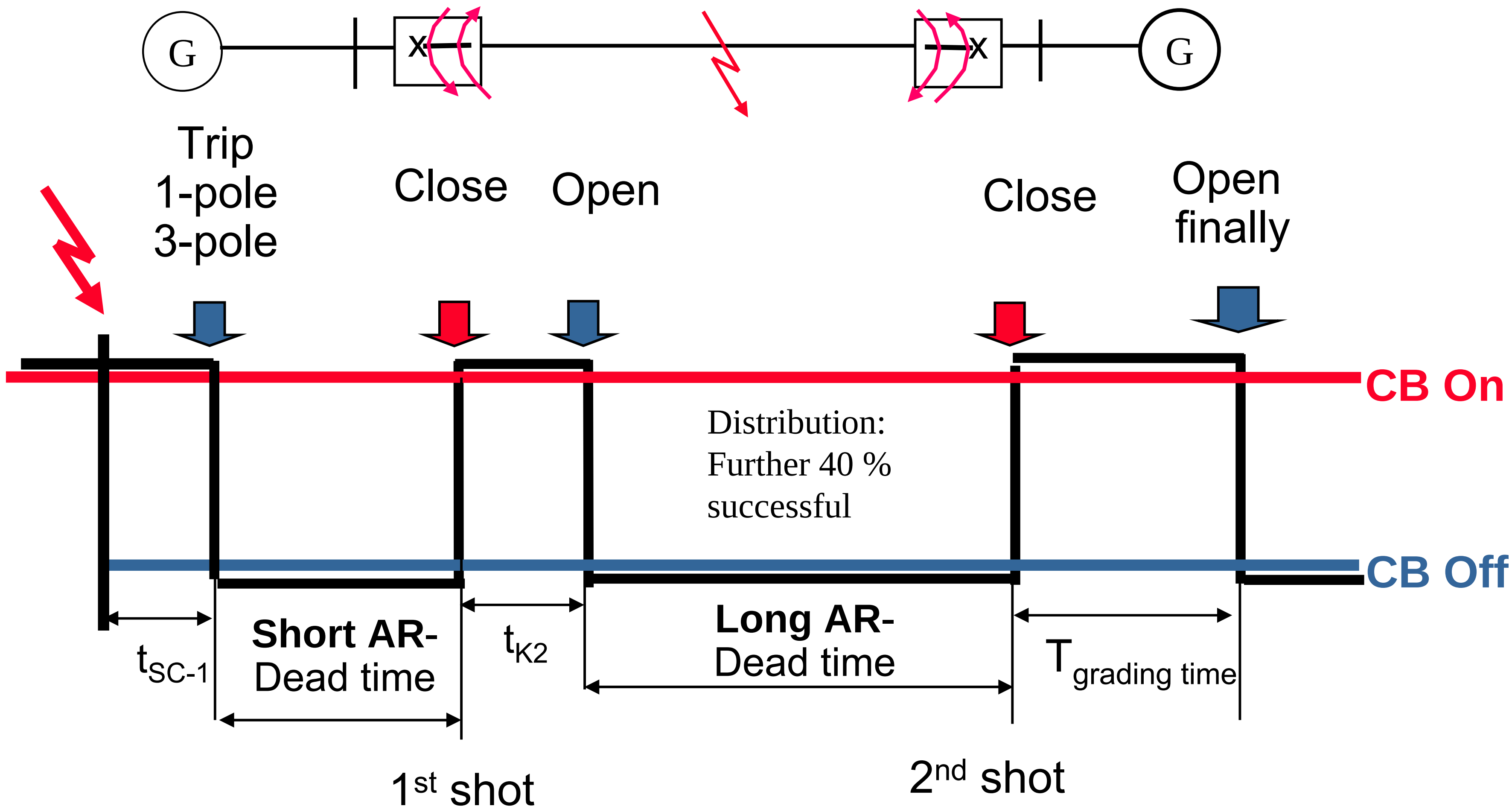
- Direction determination
- Impedance measurement, Distance to fault location
- Power measurement
- Synchro-check and Synchronising
- U<, U>, f<, f> protection



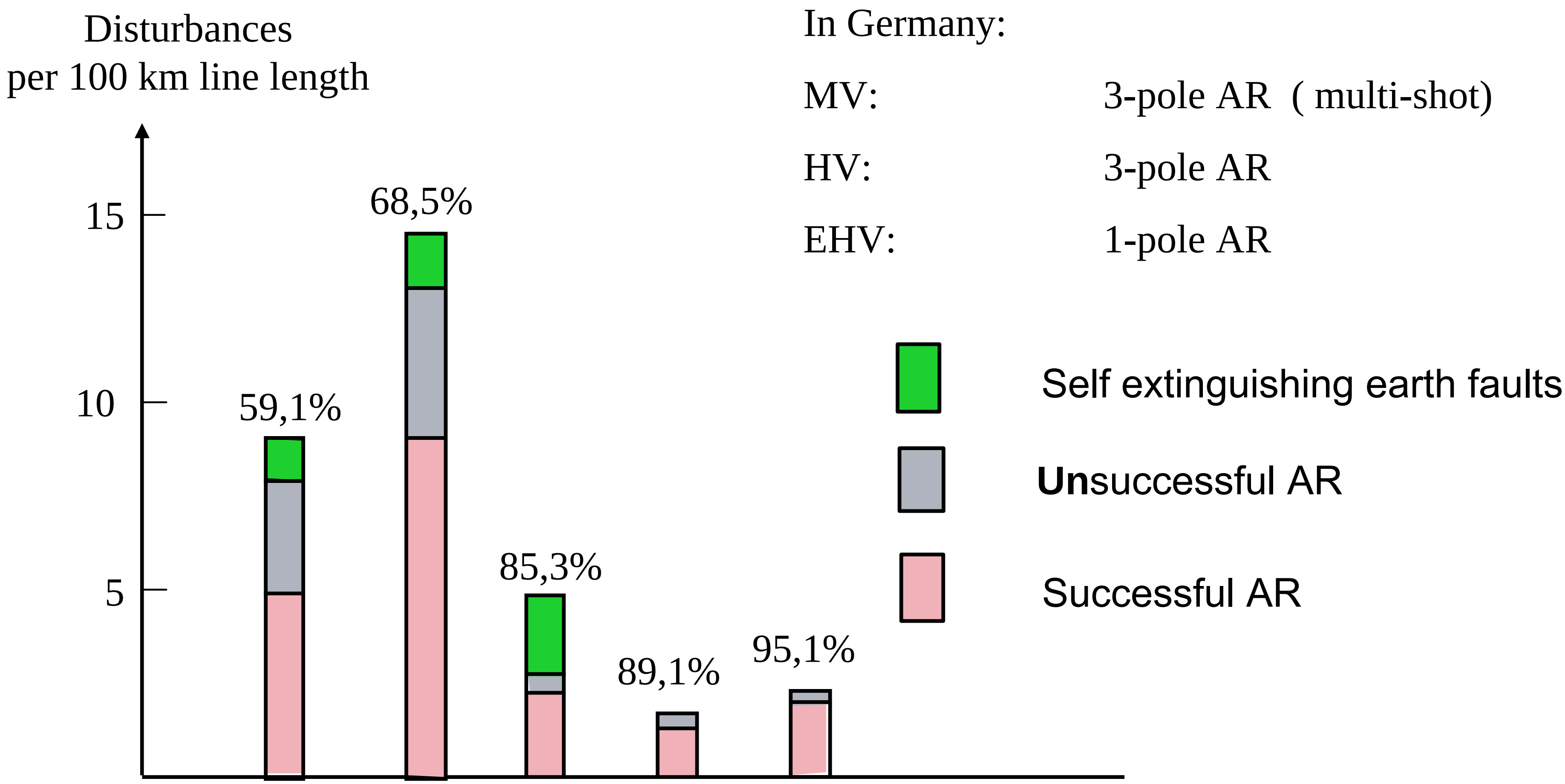
Practice:

- In distribution: VTs only at the busbar(s)
- In HV and EHV: VTs at each feeder
- Sezification according to IEC60044-2
  1% accuracy sufficient for protection

Auto-reclosure
Fast clearance of transient faults



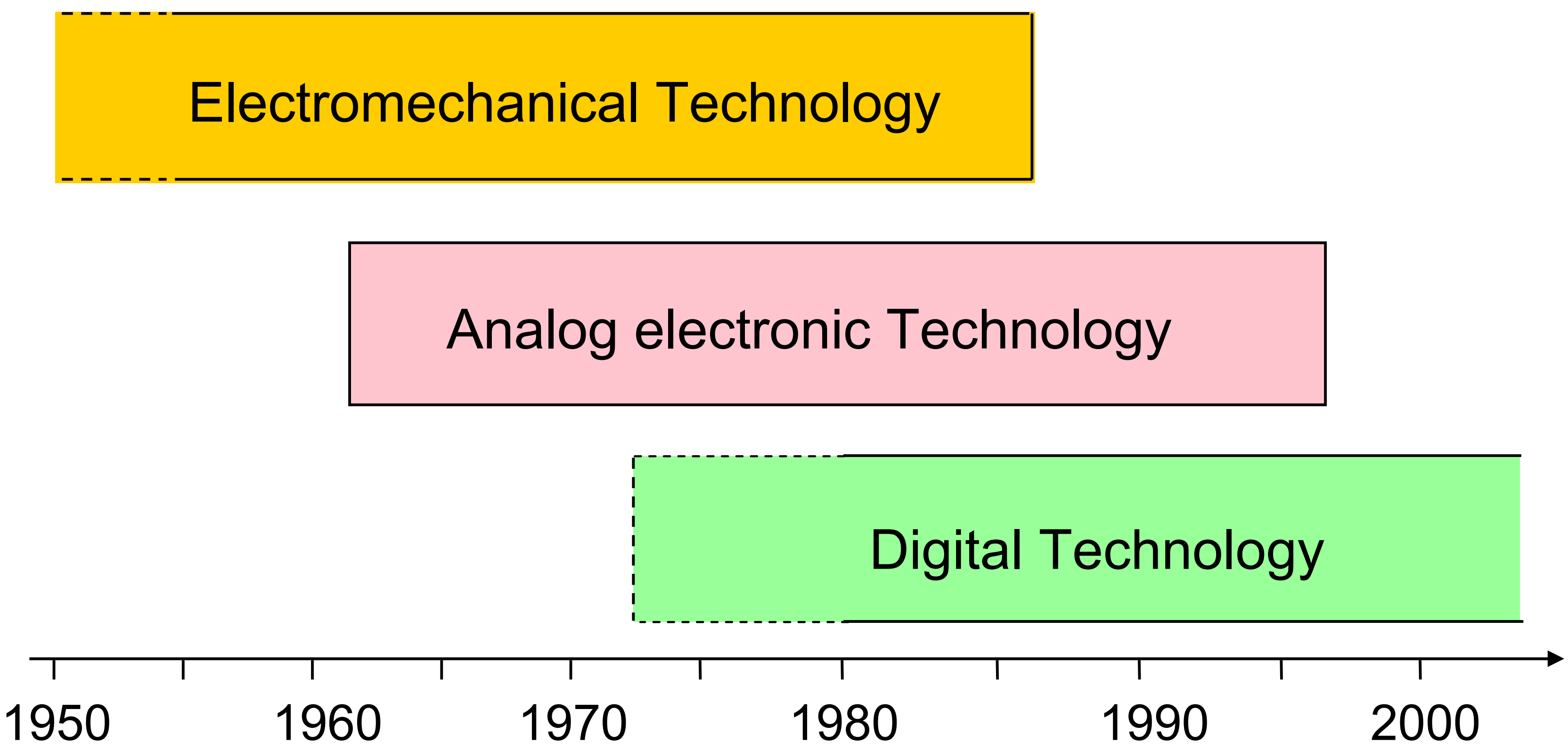
Success rate of Auto-reclosure
(German utilities, 1986)



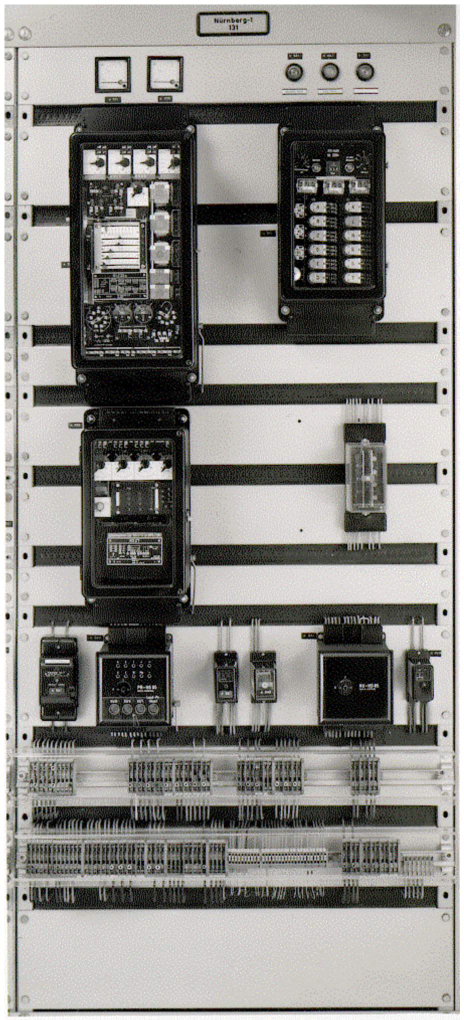
In Germany:

MV:	3-pole AR (multi-shot)
HV:	3-pole AR
EHV:	1-pole AR

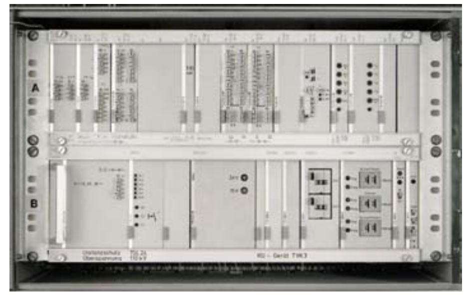
History of applied protection technology



Historic development of relay design (HV)



electromechanical



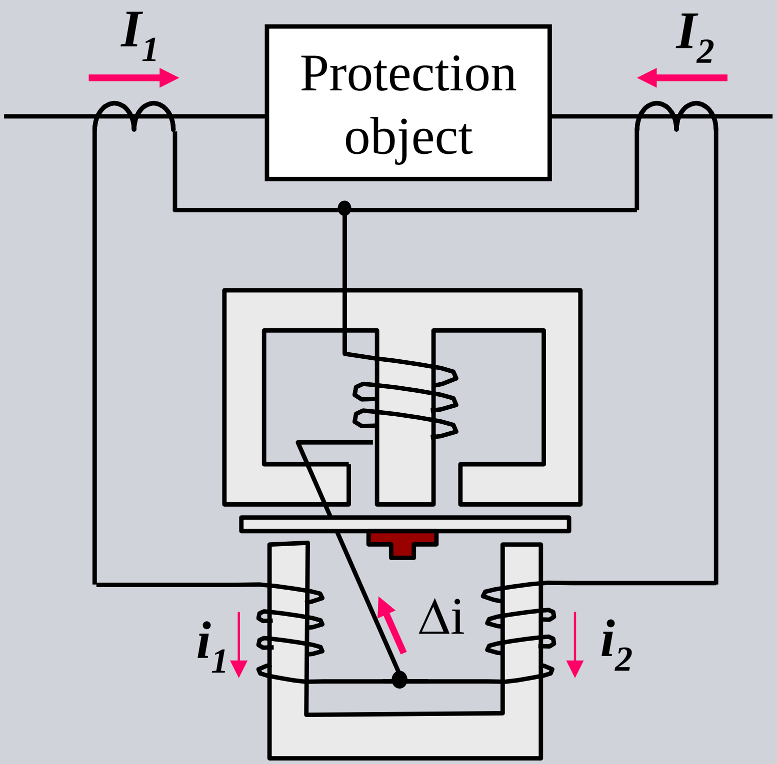
Static (analog electronic)

digital

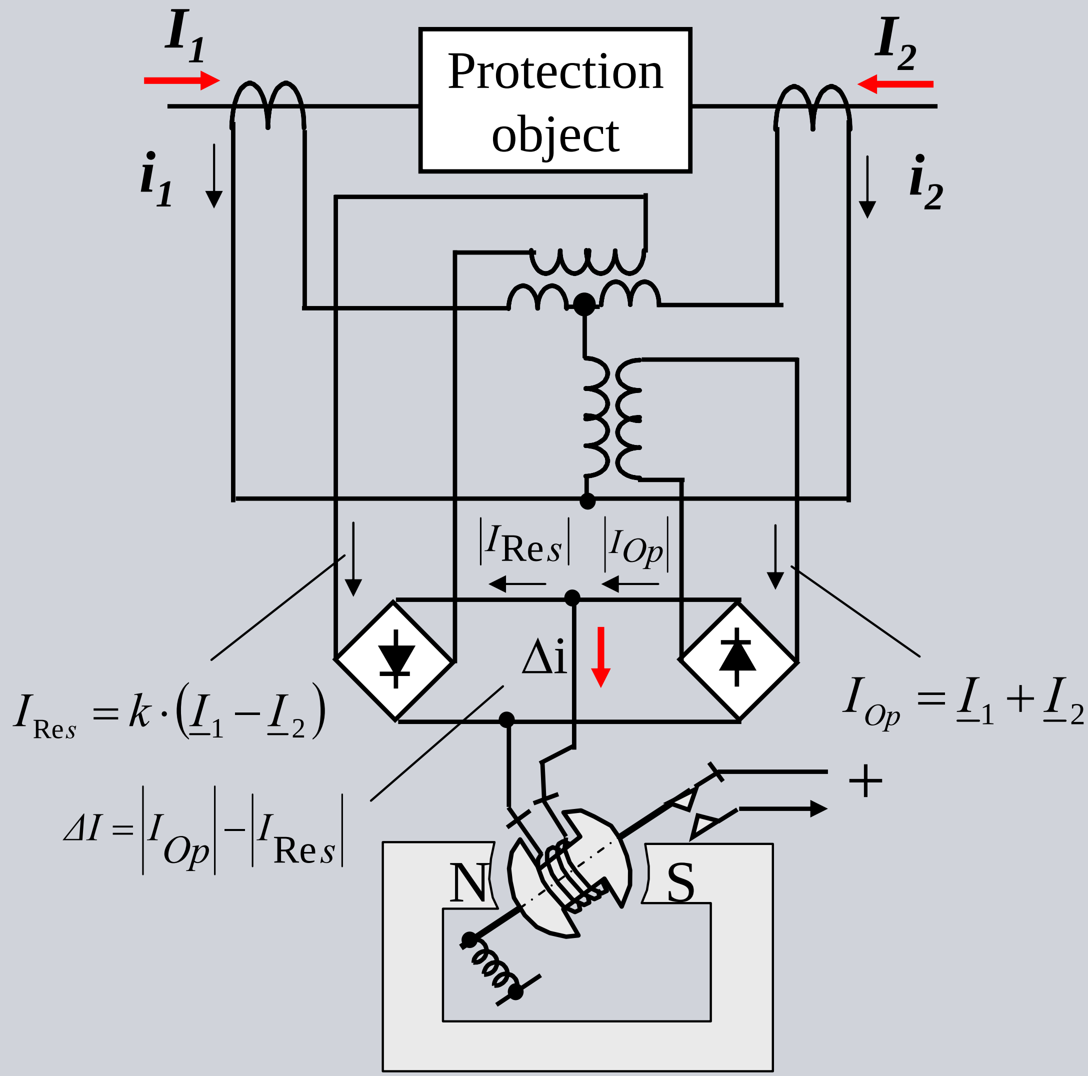
Legacy relaying technology

SIEMENS

Induction relay

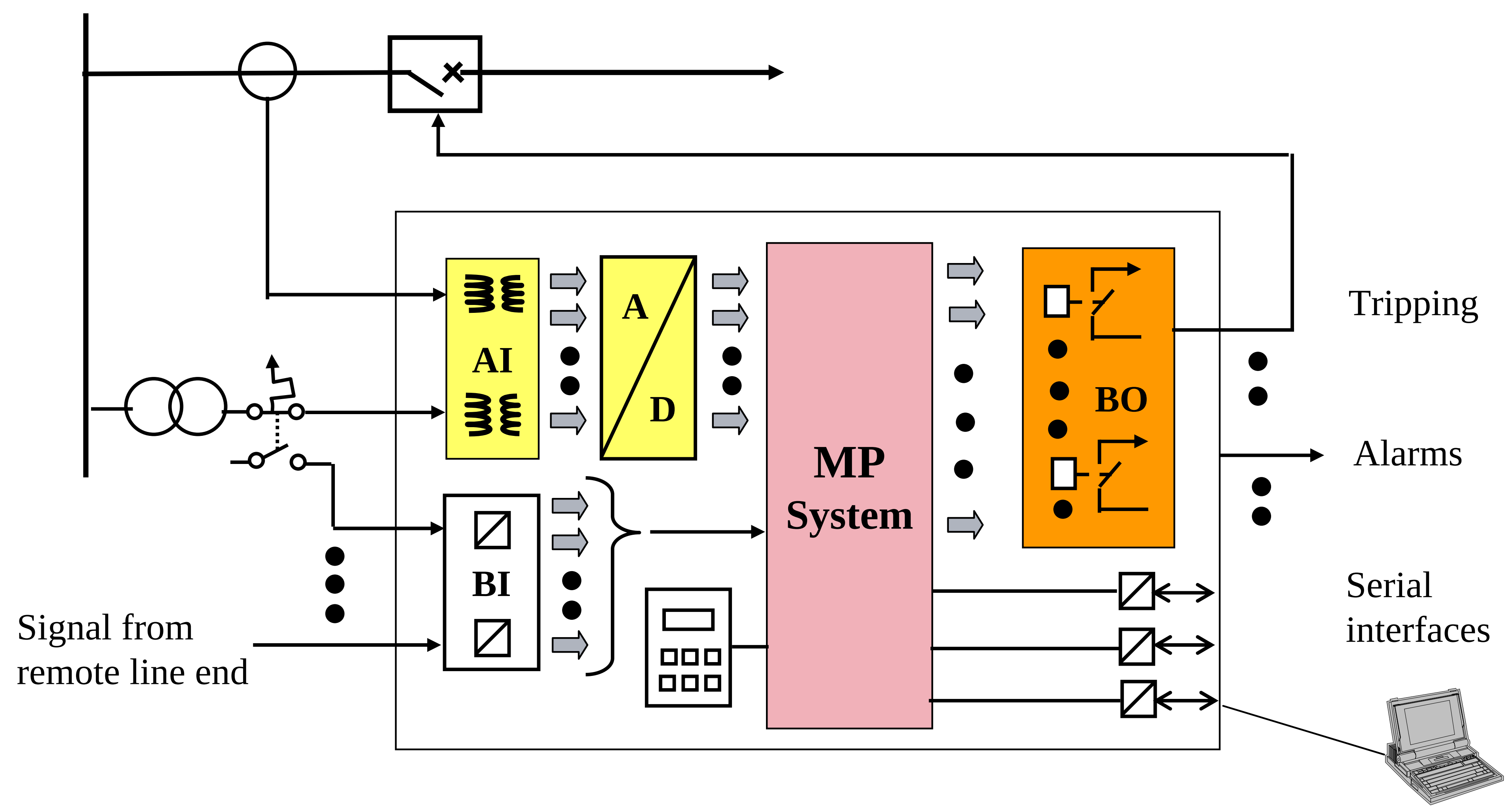


Rectifier bridge comparator with moving coil relay

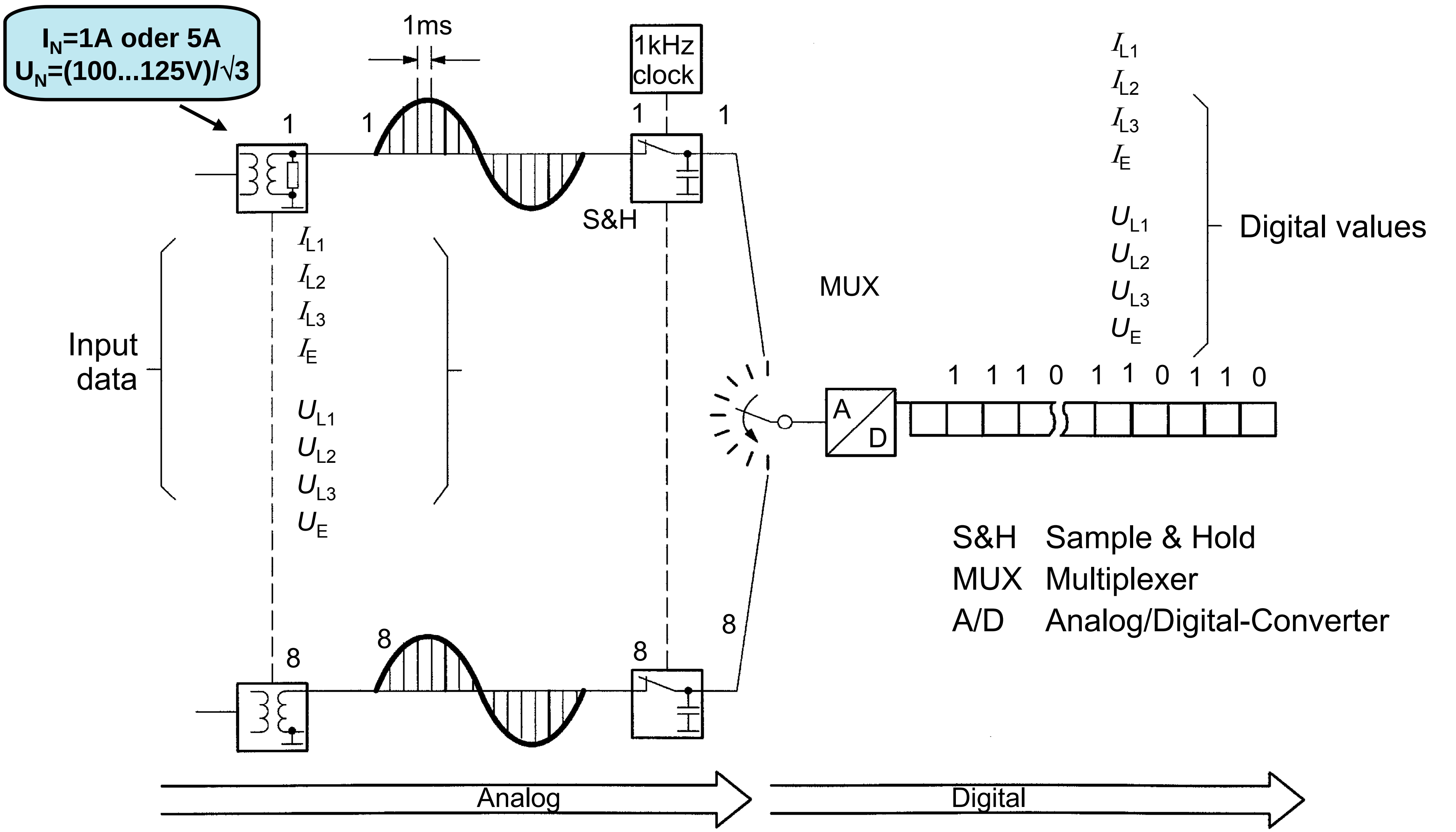


Digital relay structure

SIEMENS



Capture of measuring data (principle)

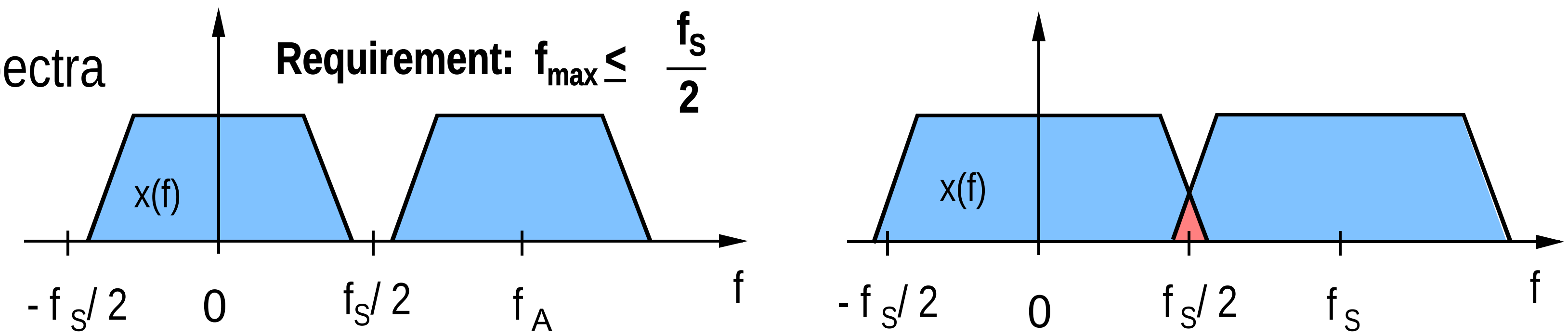


S&H Sample & Hold
MUX Multiplexer
A/D Analog/Digital-Converter

Sampling theorem

SIEMENS

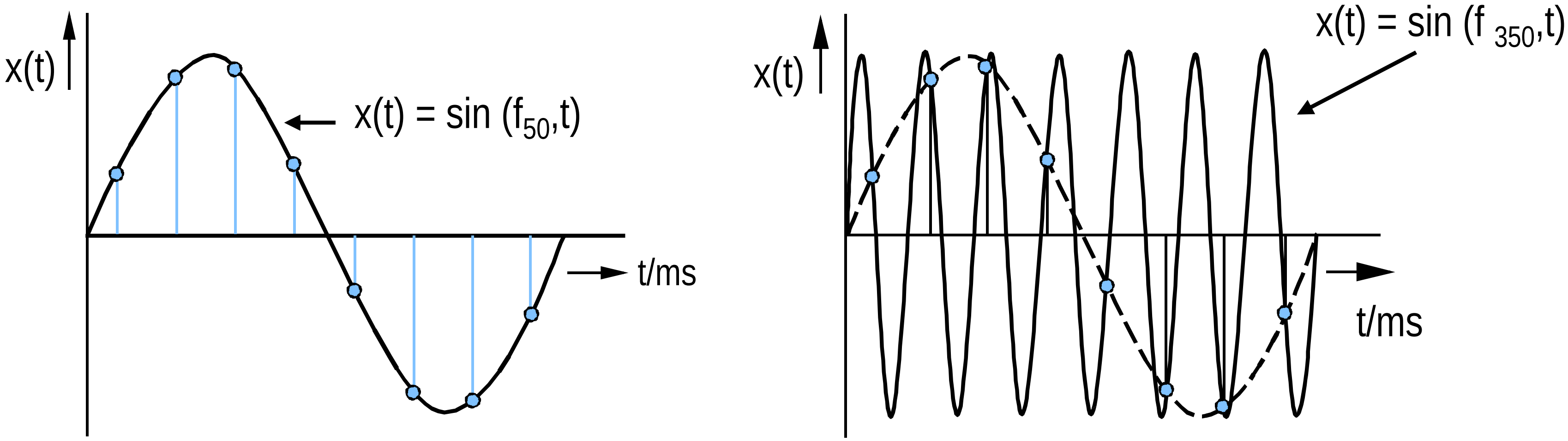
a) Spectra



Sampling theorem fulfilled!

Sampling theorem violated!

b) Sampling of different waveforms (f_S = 400Hz)



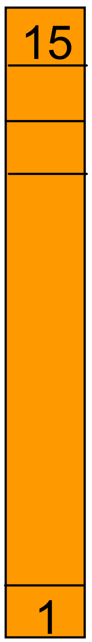
Dynamic range of A/D conversion

SIEMENS

15 bit + sign A/D converter → 15 Bit= 2^{15} =32.768 steps resolution

The measuring error corresponds to ± ½ LSB (**L**ast **S**ignificant **B**it)

Currents:

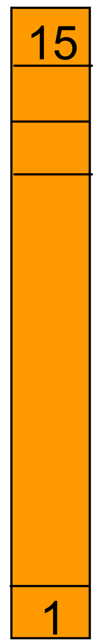


32.768 steps = 100 x I_N

33 steps = 0.1 x In
→ Error: 1.5 % of the measuring value

1 step = 0.00305 x I_N = 0.3 % x I_N

Voltages:



32.768 steps = 140 V

234 steps = 1.0 V
→ Error: 0.2 % of the measuring value

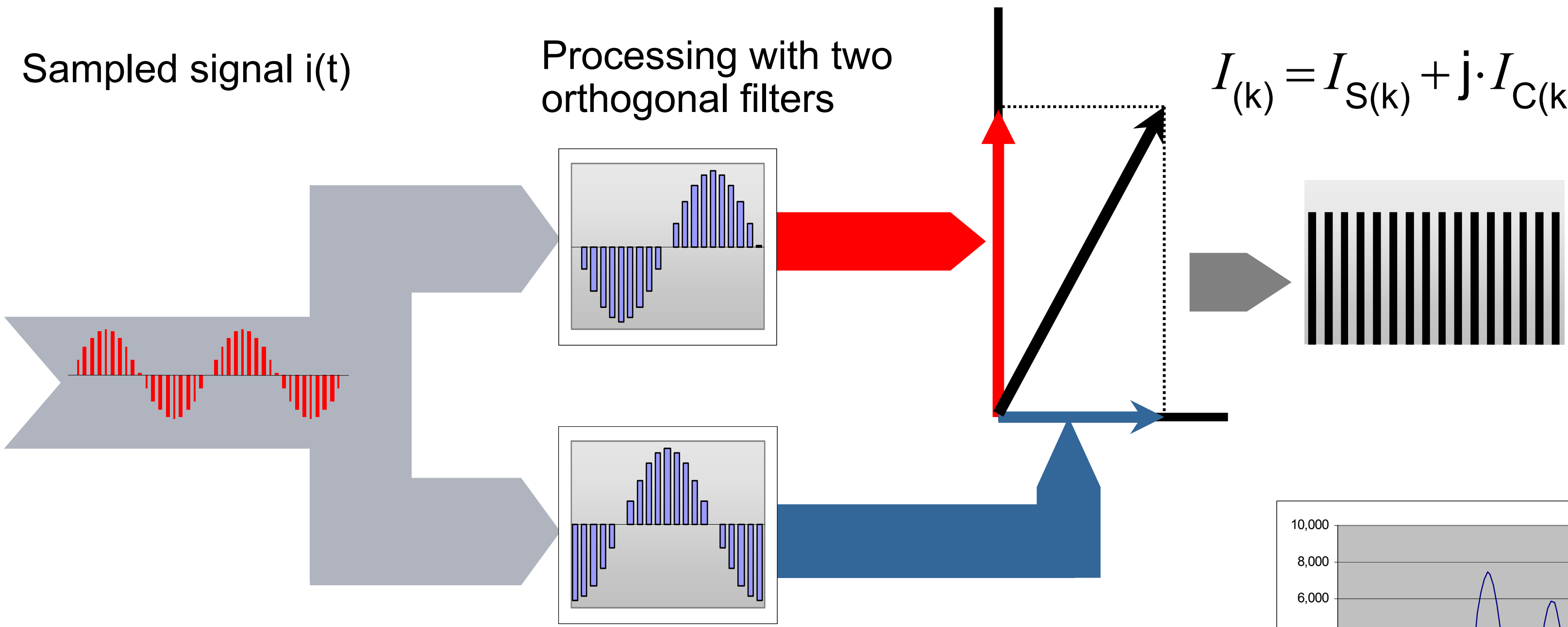
1 step = 0.00427 V

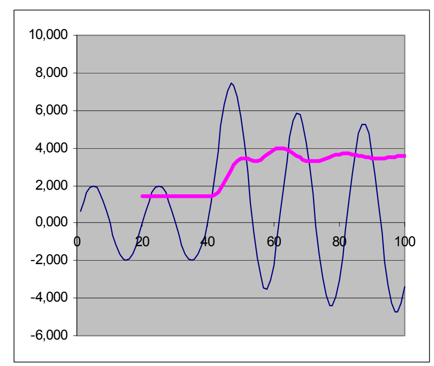
Fourier analysis of measured values

Sampled signal i(t)

Processing with two orthogonal filters

$$I_{(k)} = I_{S(k)} + j \cdot I_{C(k)}$$

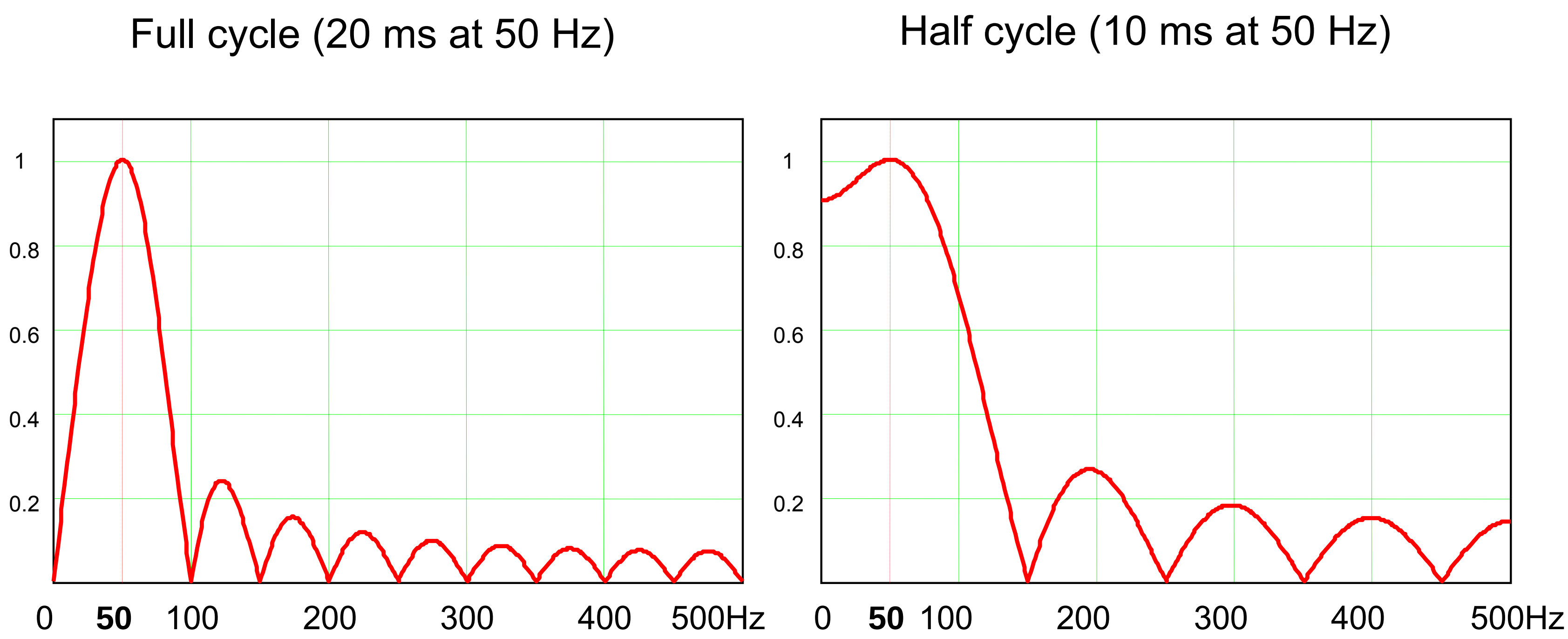




$$I_S = \frac{1}{2\pi} \int_{\varnothing - 360°}^{\varnothing} I(\omega t) \cdot \sin \omega t \, dt$$

$$I_C = \frac{1}{2\pi} \int_{\varnothing - 360°}^{\varnothing} I(\omega t) \cdot \cos \omega t \, dt$$

Fourier analysis: Filtering characteristics



Fourier transform
Determination of Voltage and current phasors

SIEMENS

$$u_L(t) = R_L \cdot i_L(t) + L_L \cdot \frac{di_L(t)}{dt}$$

$$Re\{\underline{U}_L\} = \frac{1}{T} \cdot \int_{-T/2}^{+T/2} u_L(t) \cdot \cos(\omega_0 \cdot t)\,dt$$

$$Im\{\underline{U}_L\} = \frac{1}{T} \cdot \int_{-T/2}^{+T/2} u_L(t) \cdot \sin(\omega_0 \cdot t)\,dt$$

$$\underline{U}_L = Re\{\underline{U}_L\} + jIm\{\underline{U}_L\}$$

$$Re\{\underline{I}_L\} = \frac{1}{T} \cdot \int_{-T/2}^{+T/2} i_L(t) \cdot \cos(\omega_0 \cdot t)\,dt$$

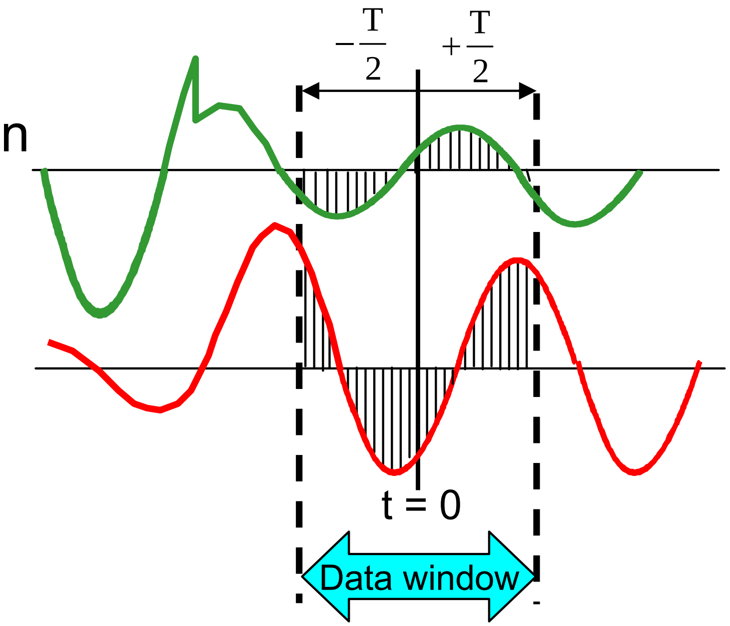
$$Im\{\underline{I}_L\} = \frac{1}{T} \cdot \int_{-T/2}^{+T/2} i_L(t) \cdot \sin(\omega_0 \cdot t)\,dt$$

$$\underline{I}_L = Re\{\underline{I}_L\} + jIm\{\underline{I}_L\}$$

$$\underline{U}_L = U_L \cdot [\cos(\omega \cdot t + \varphi_U) + j\sin(\omega \cdot t + \varphi_U)] = U_L \cdot e^{j(\omega t + \varphi_U)}$$

$$\underline{I}_L = I_L \cdot [\cos(\omega \cdot t + \varphi_I) + j\sin(\omega \cdot t + \varphi_I)] = I_L \cdot e^{j(\omega t + \varphi_I)}$$

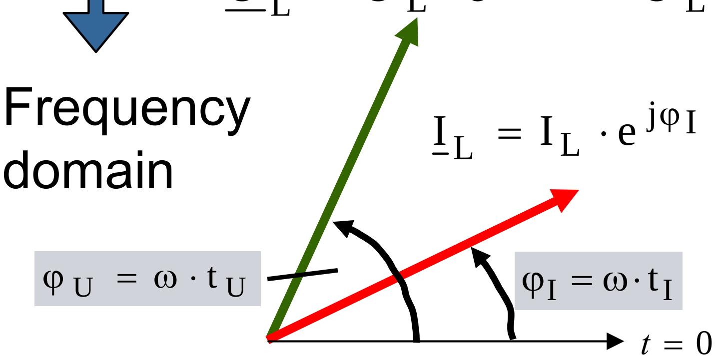
Time domain



Frequency domain

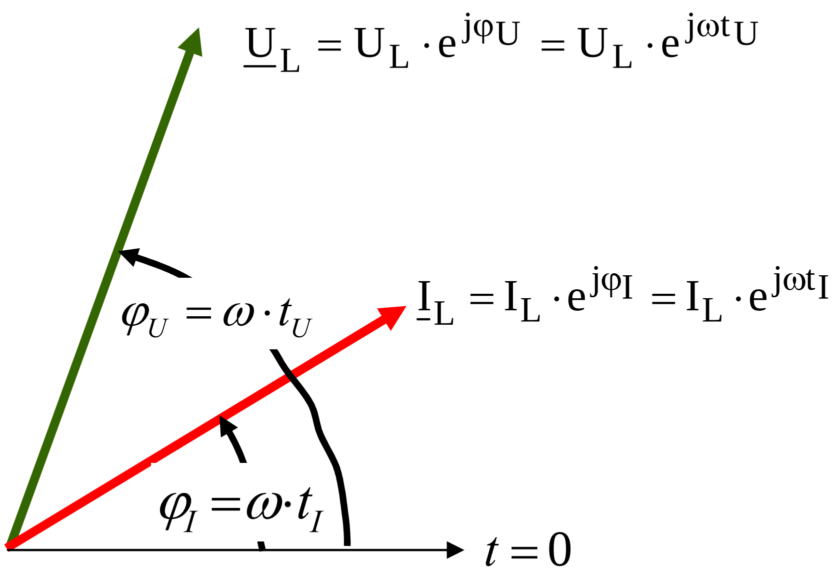
$$\underline{U}_L = U_L \cdot e^{j\varphi_U} = U_L \cdot e^{j\omega t_U}$$

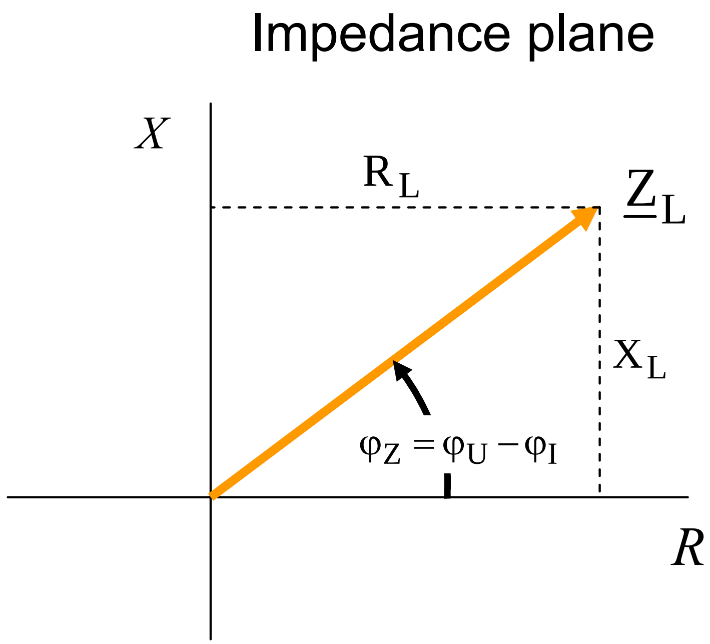
$$\underline{I}_L = I_L \cdot e^{j\varphi_I} = I_L \cdot e^{j\omega t_I}$$



Fault impedance calculation
from complex U- and I-phasors for distance protection

SIEMENS





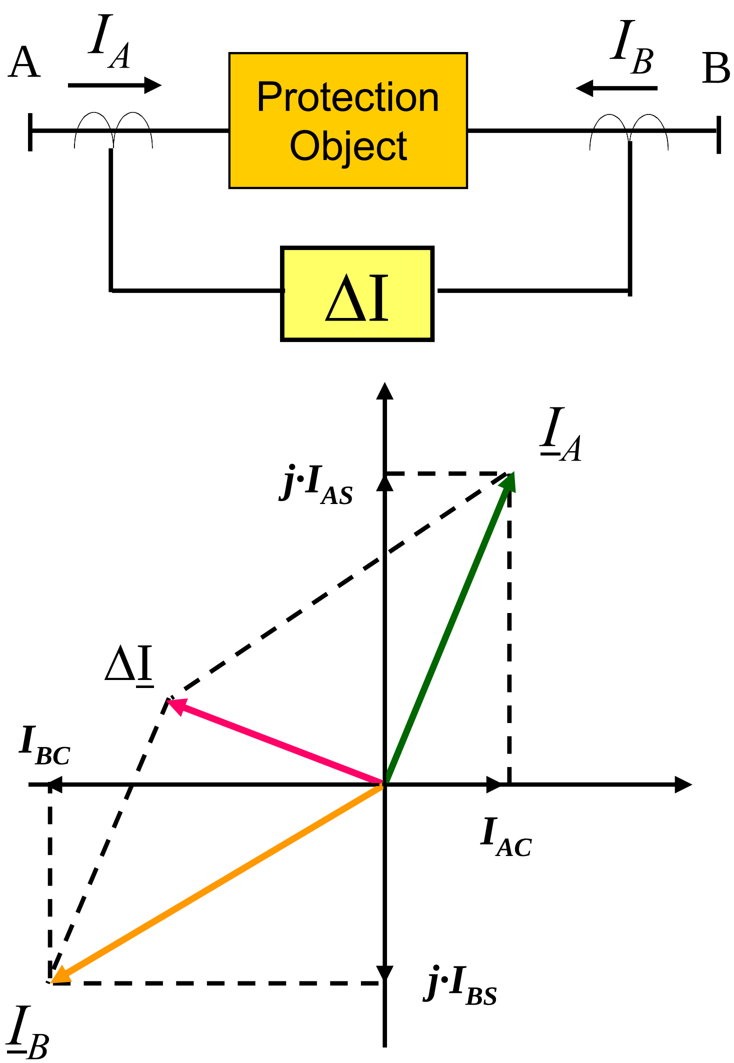
$$\underline{Z}_L = \frac{\underline{U}_L}{\underline{I}_L} = \frac{U_L \cdot e^{j\varphi_U}}{I_L \cdot e^{j\varphi_I}} = \frac{U_L}{I_L} \cdot e^{j(\varphi_U - \varphi_I)}$$

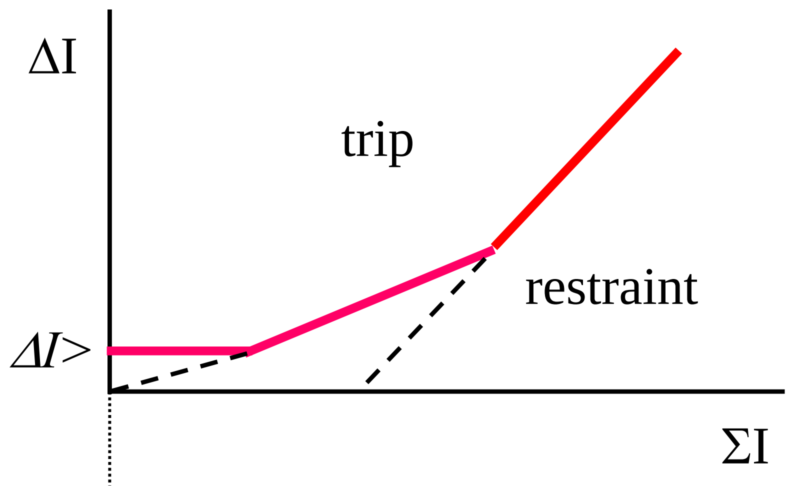
$$= R_L + jX_L$$

$$R_L = \mathrm{Re}\{\underline{Z}_L\} = \frac{U_L}{I_L} \cdot \cos(\varphi_U - \varphi_I)$$

$$X_L = \mathrm{Im}\{Z_L\} = \frac{U_L}{I_L} \sin(\varphi_U - \varphi_I)$$

Differential protection with current phasors (principle)





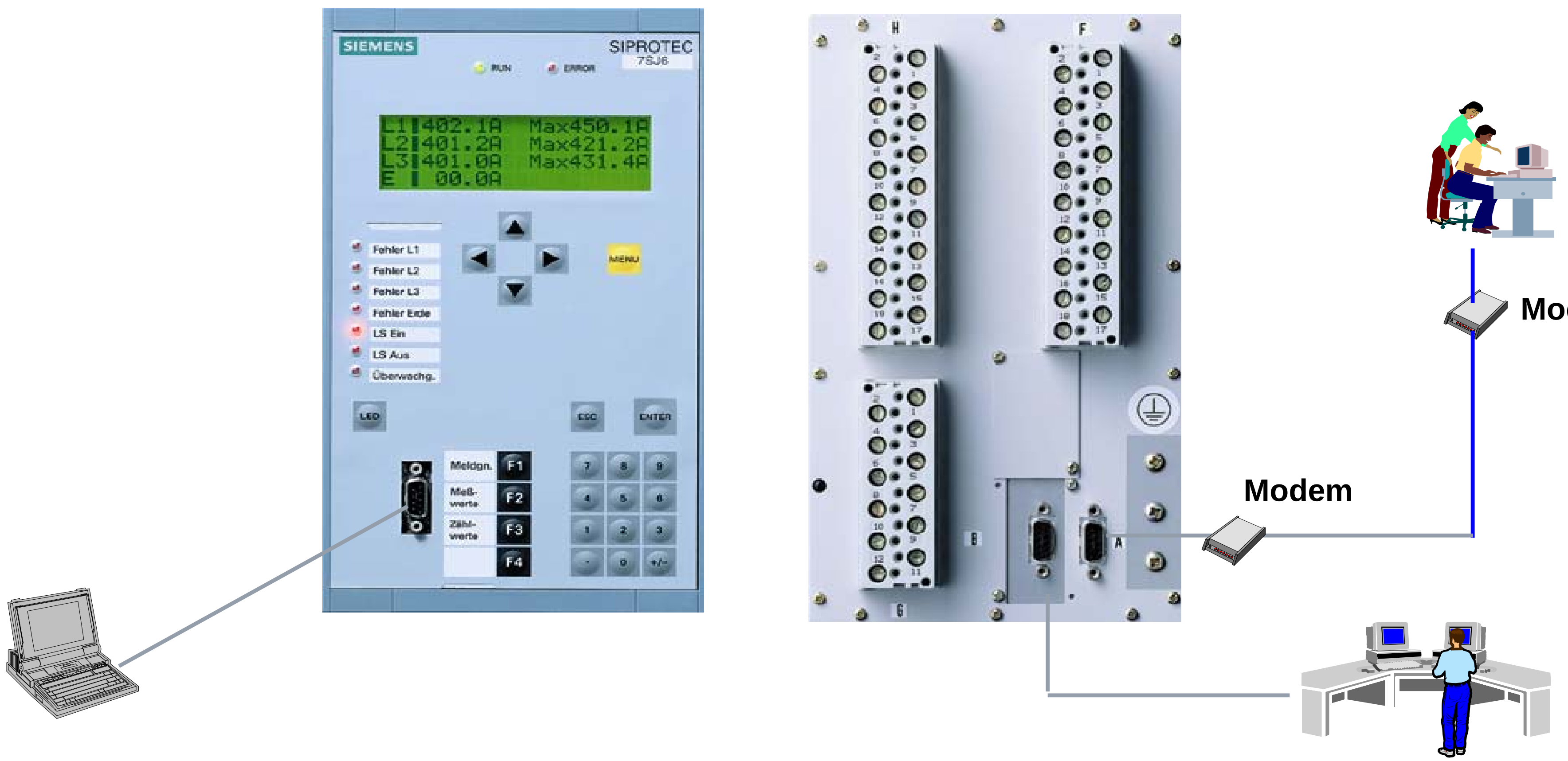
Operating quantity : $\Delta I = \left| I_A + I_B \right|$

Restraining quantity : $\Sigma I = \left| I_A \right| + \left| I_B \right|$

Power System Protection:
Digital relay design (different manufacturers)

Uniform Design Trend

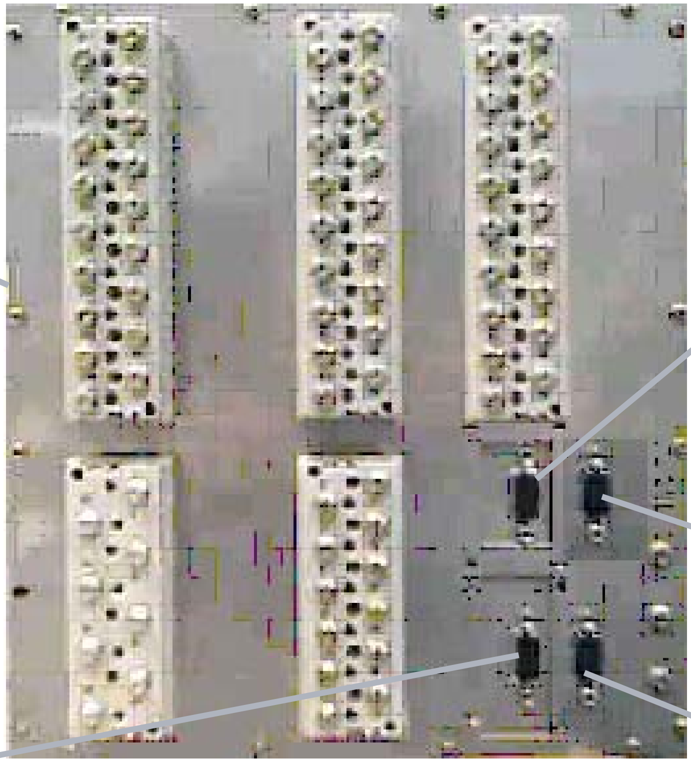
Modern digital protection relay, design



Relay series SIPROTEC 4
Communication interfaces (1)

SIEMENS

PC-interface,
front side
⇨electric RS 232



Analog output 20 mA or
teleprotection interface
⇨electric or optic

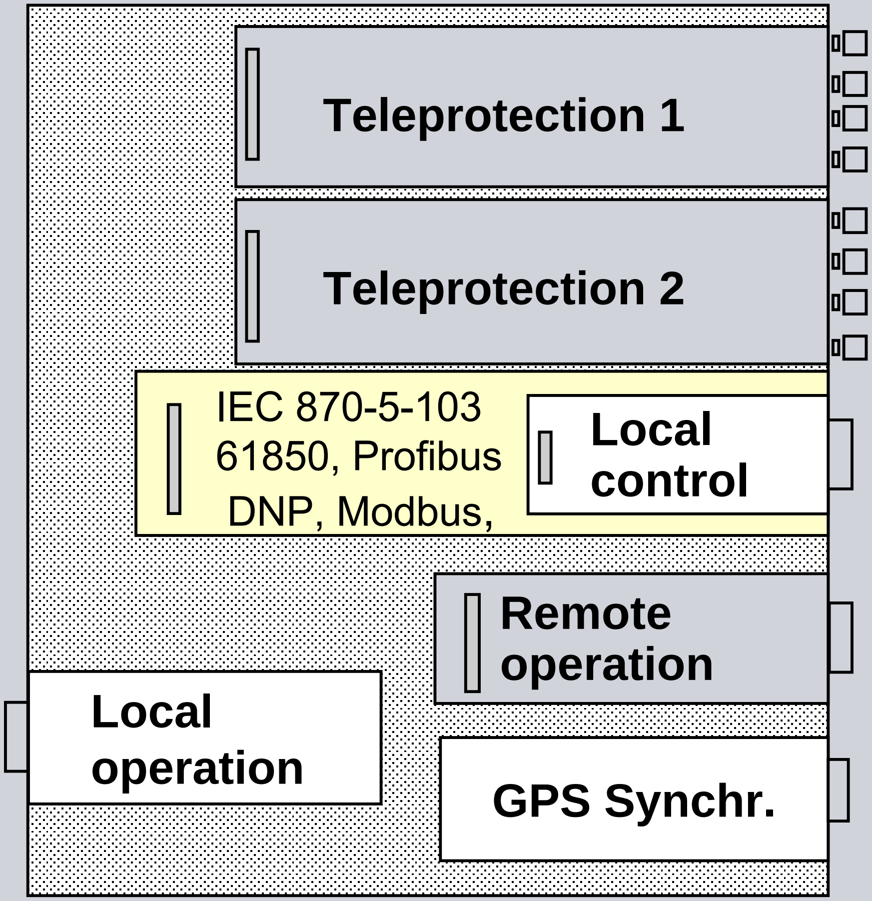
Service interface
⇨electric RS232 / RS485
⇨DIGSI 4 / modem

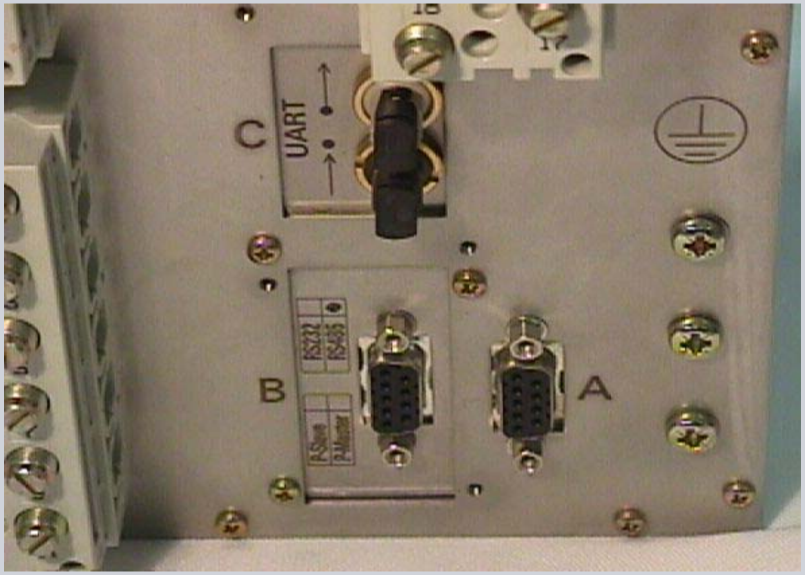
System interface
⇨electric or optic
⇨IEC60870-5-103,IEC61850, Profibus FMS,
DNP3.0 or Modbus;
alternatively analog output 20 mA

Time synchronisation
⇨GPS (IREC-B)
⇨or DCF-77

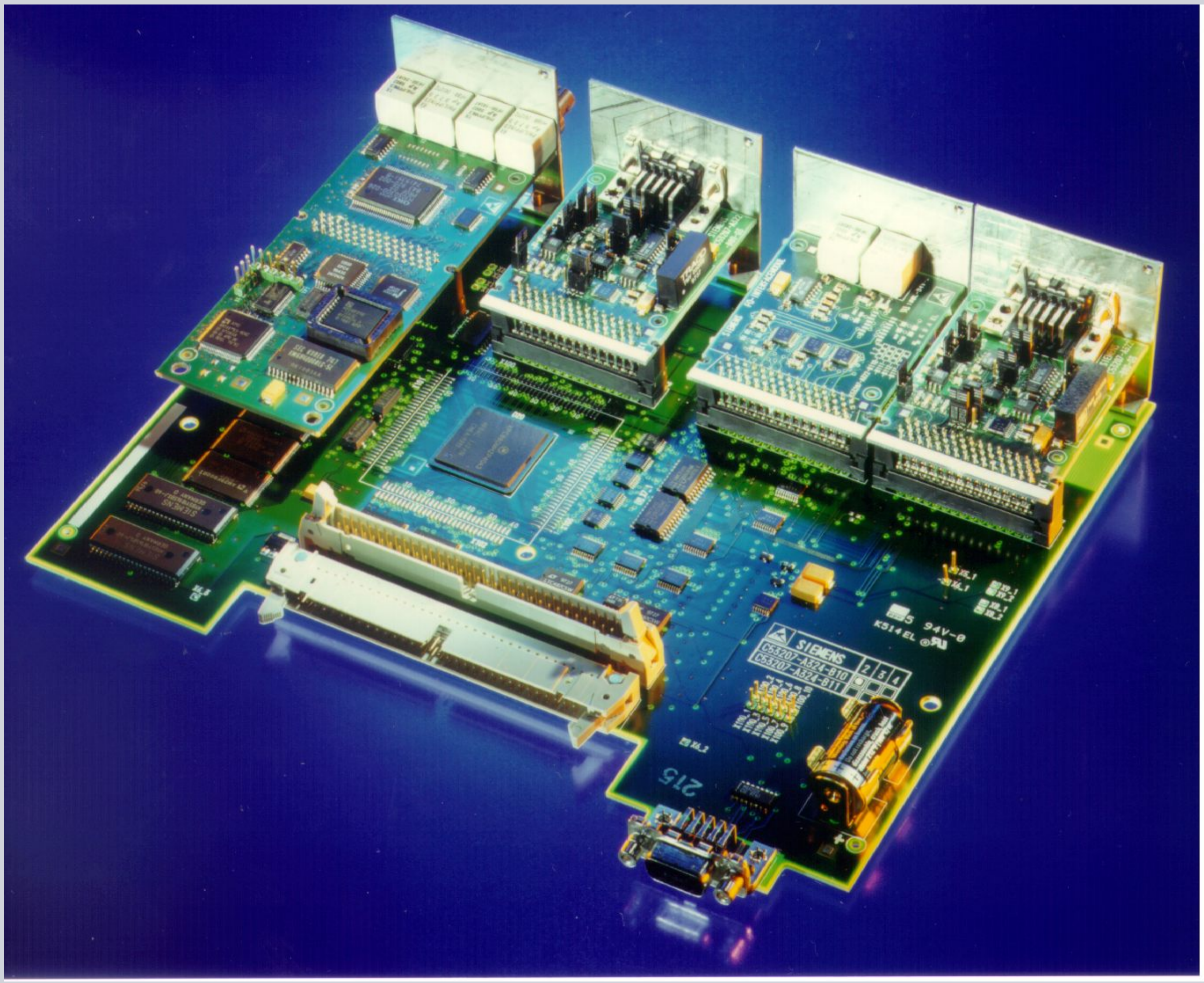
Relay series SIPROTEC 4
Communication interface (2)

SIEMENS

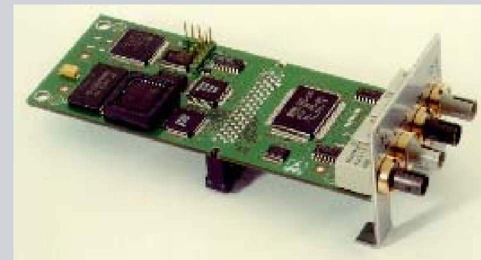




Main processing bord
and communication interface modules (SIPROTEC 4 relay series)



O.F. Double ring



Exchangeable communication modules

Wired IEC61850 Ethernet 100 Mbit

Development of relay processing hardware

SIEMENS

Begin of delivery	Relay generation	Memories RAM/EPROM	Bus width	Clock frequency	Processing power
1992	SIPROTEC 3	256/512 k	16 bit	16 MHz	1.0 MIPS *)
2000	SIPROTEC 4	512k/4MB + 4MB D-RAM	32 bit	80 MHz	35 MIPS *)

*) MIPS: Million Instructions per second

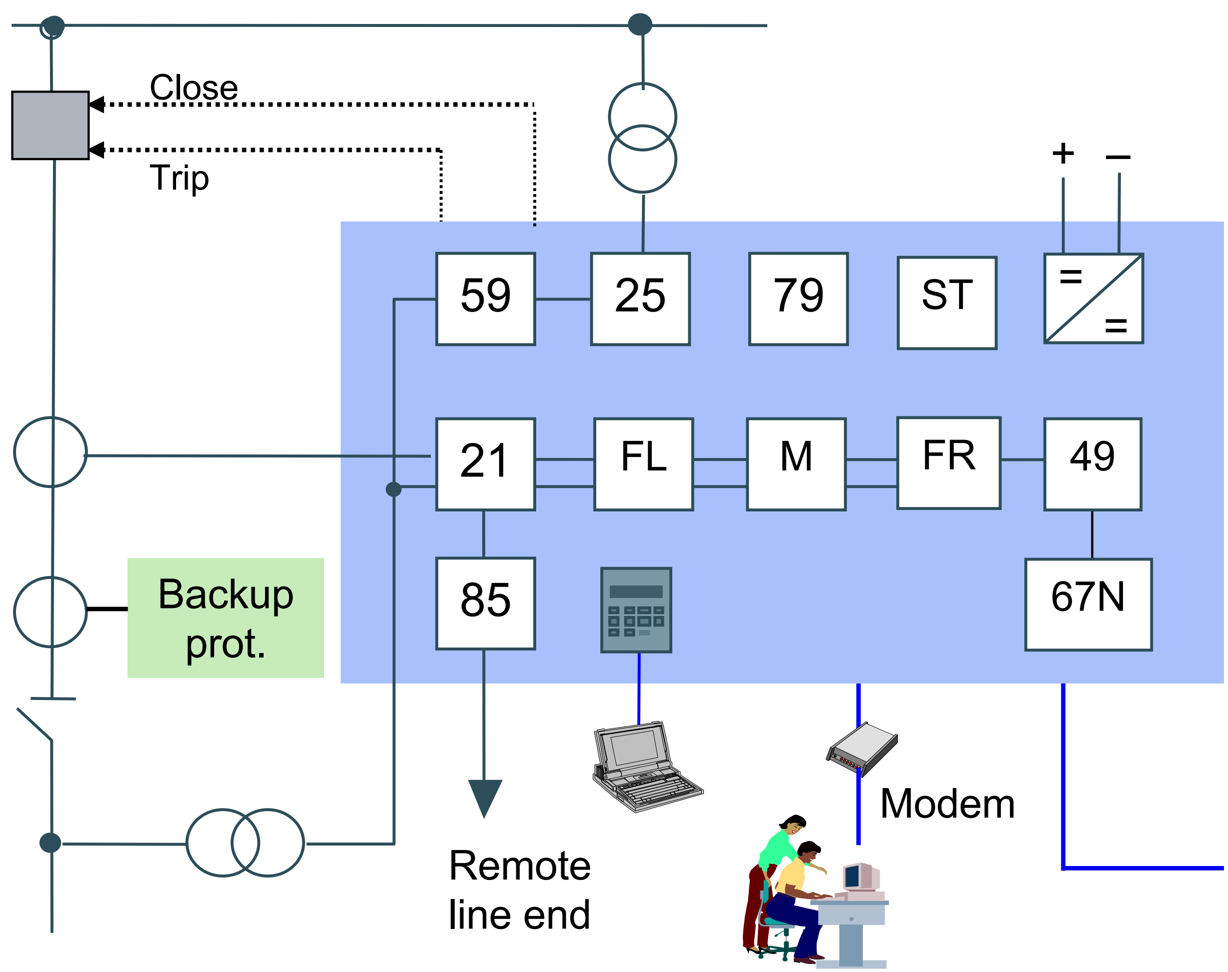
Digital Relay, Data aquisition
SIPROTEC 4 relay series

SIEMENS

Sampling rate:	1000 Hz (1200 Hz at 60 Hz nominal frequency)
Samples per period:	20
Anti-aliasing filter:	500 Hz (600 Hz) limiting frequency
A/D-conversion:	16 bit, corresponding to 65536 steps
Measuring value storage:	15 s
Program language:	C/C++

Multi-function digital relay

Example Feeder protection



59	Overvoltage
25	Synchro-check
79	Auto-reclosure
ST	Control
21	Distance protection
FL	Fault locator
FR	fault recording
M	Measurement
49	Overload
67N	Directional EF protection
85	Teleprotection supplement

Combined Protection and Control devices

SIEMENS

Scope of functions:

- **Protection**
- **Monitoring**
- **Measuring (Load monitoring)**
- **Control**
- **Automisation**
- **Data capture and storage**
- **Communication**

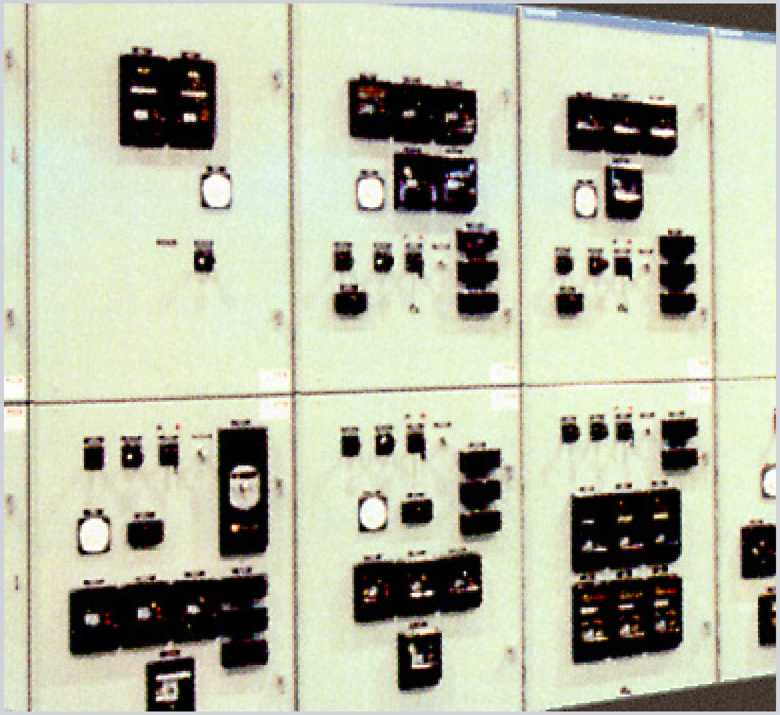
One feeder, one relay!

IED: Intelligent electronic device

Distribution Switchgear Innovation

One IED replaces a conglomeration of “black box” devices

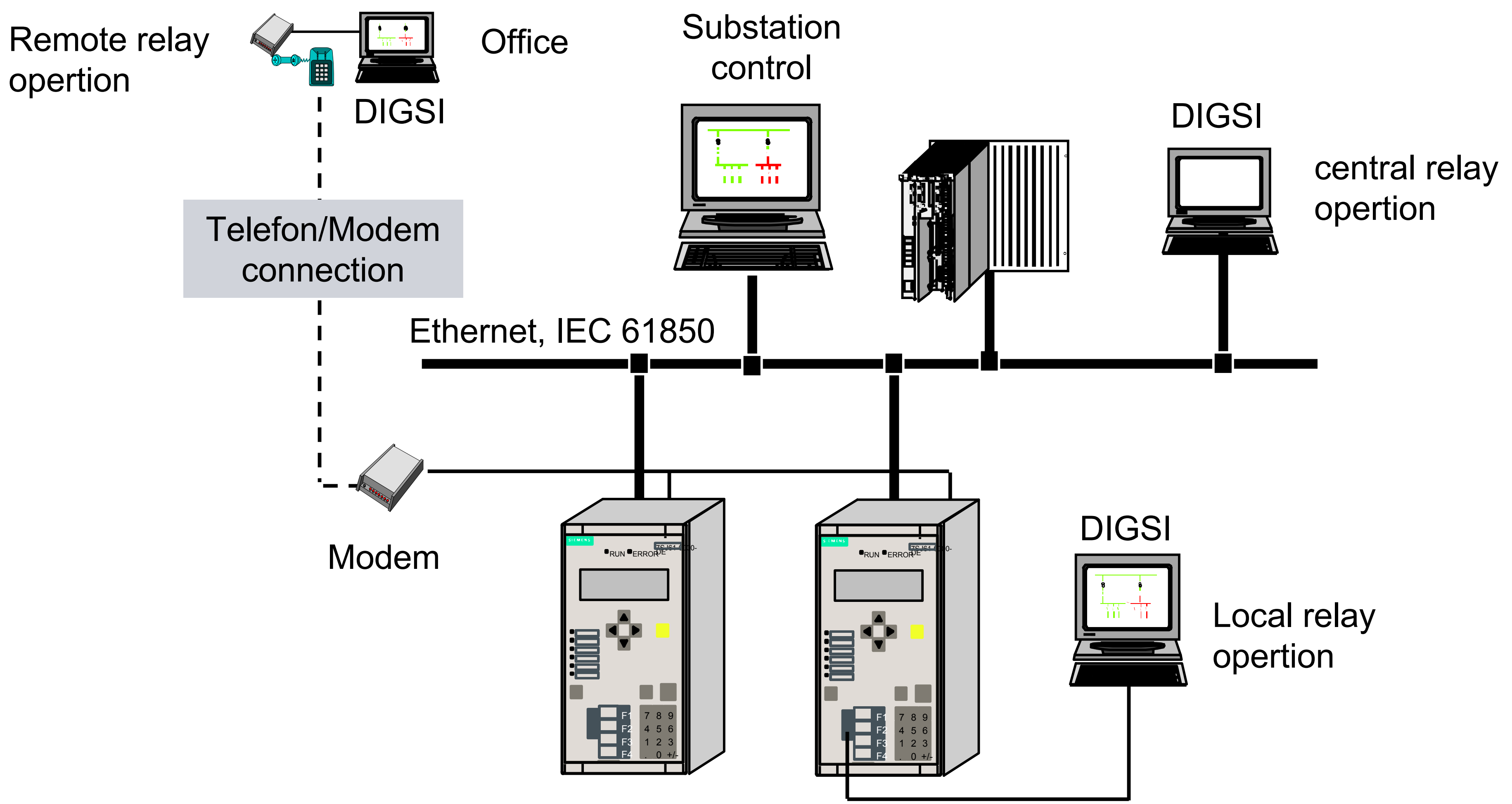
Traditional panels
with mechanical relays and control



Modern panels with
digital multifunction relays

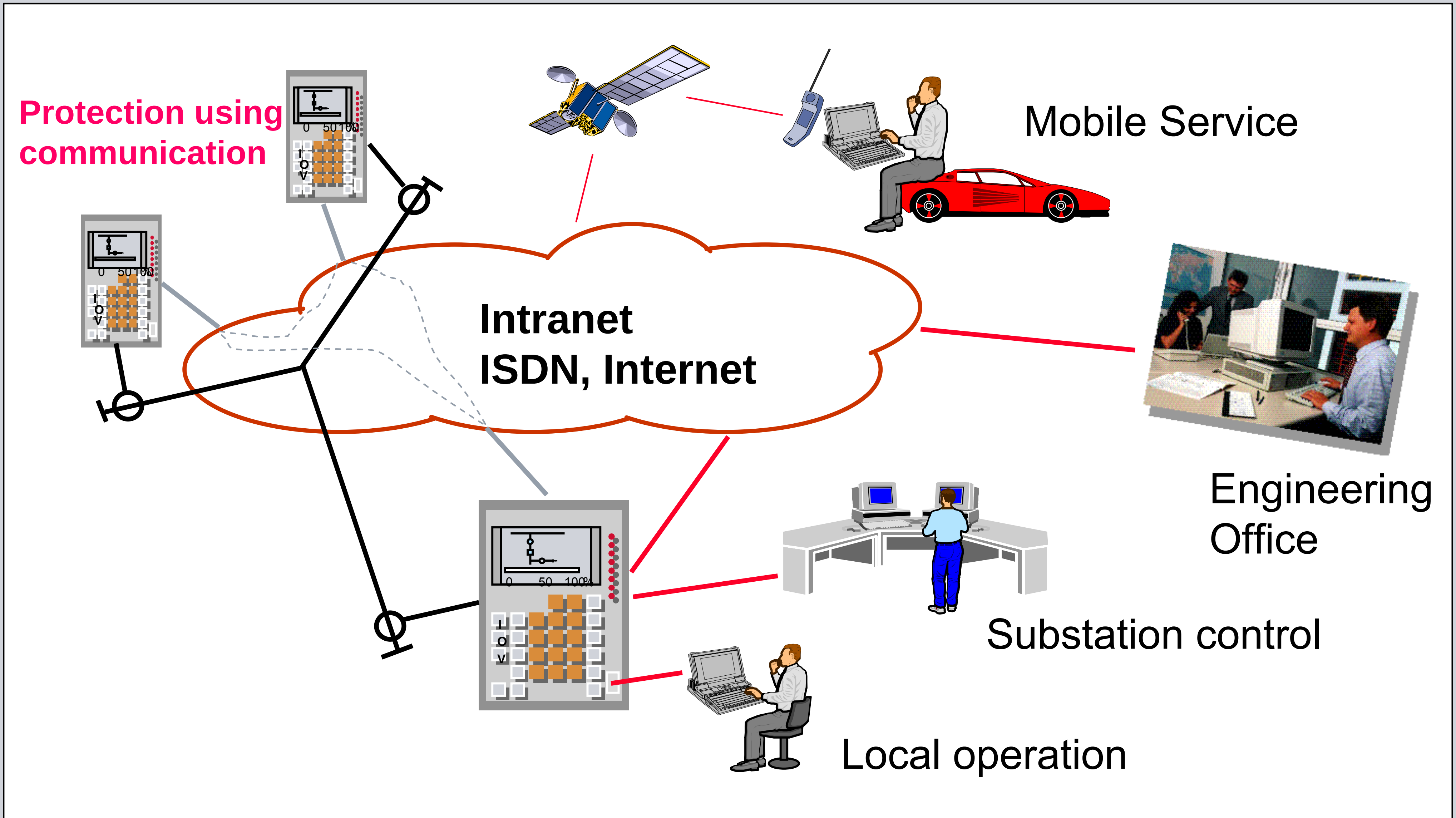
Relays as components of Substation Automation

SIEMENS



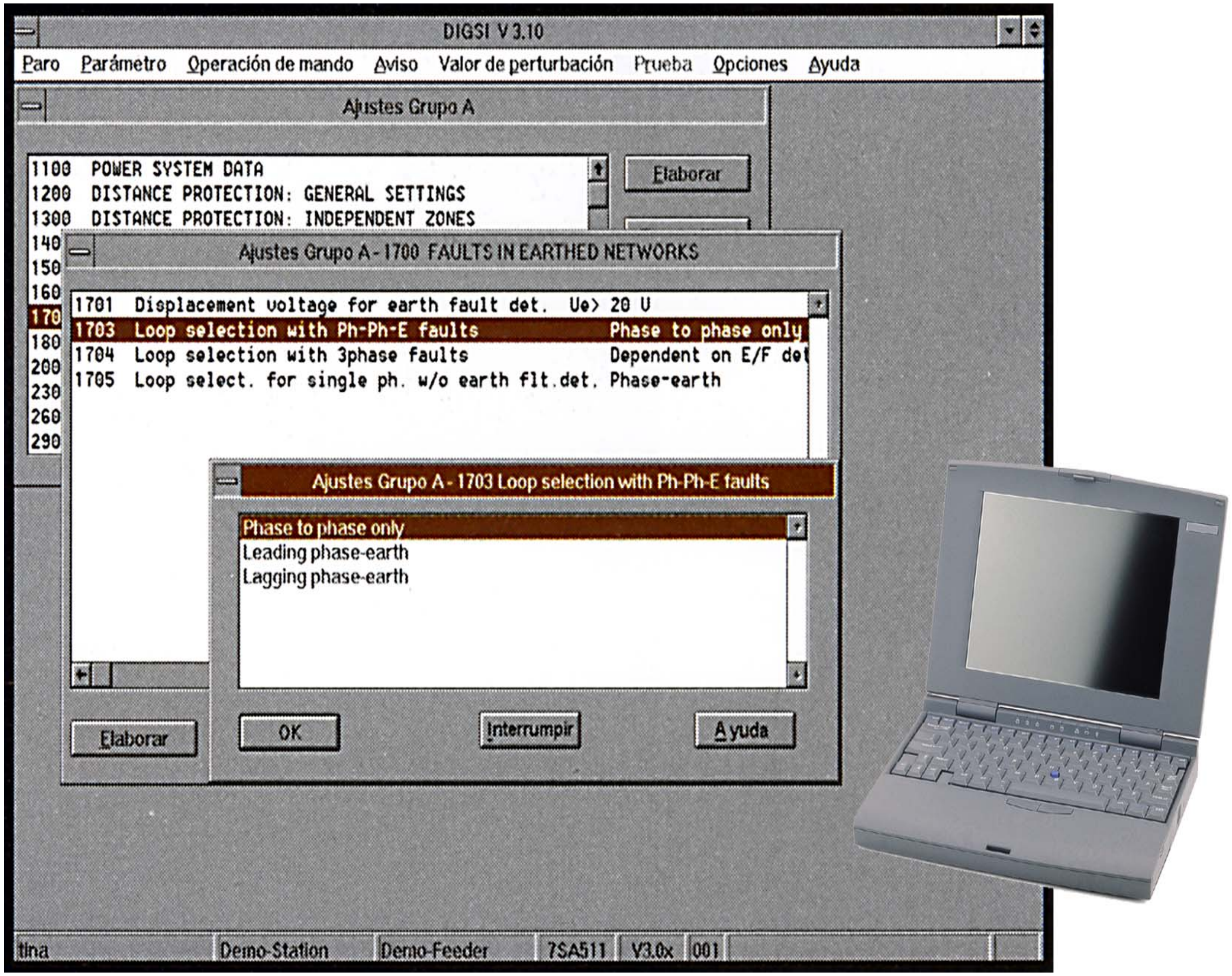
Relay communication options

SIEMENS

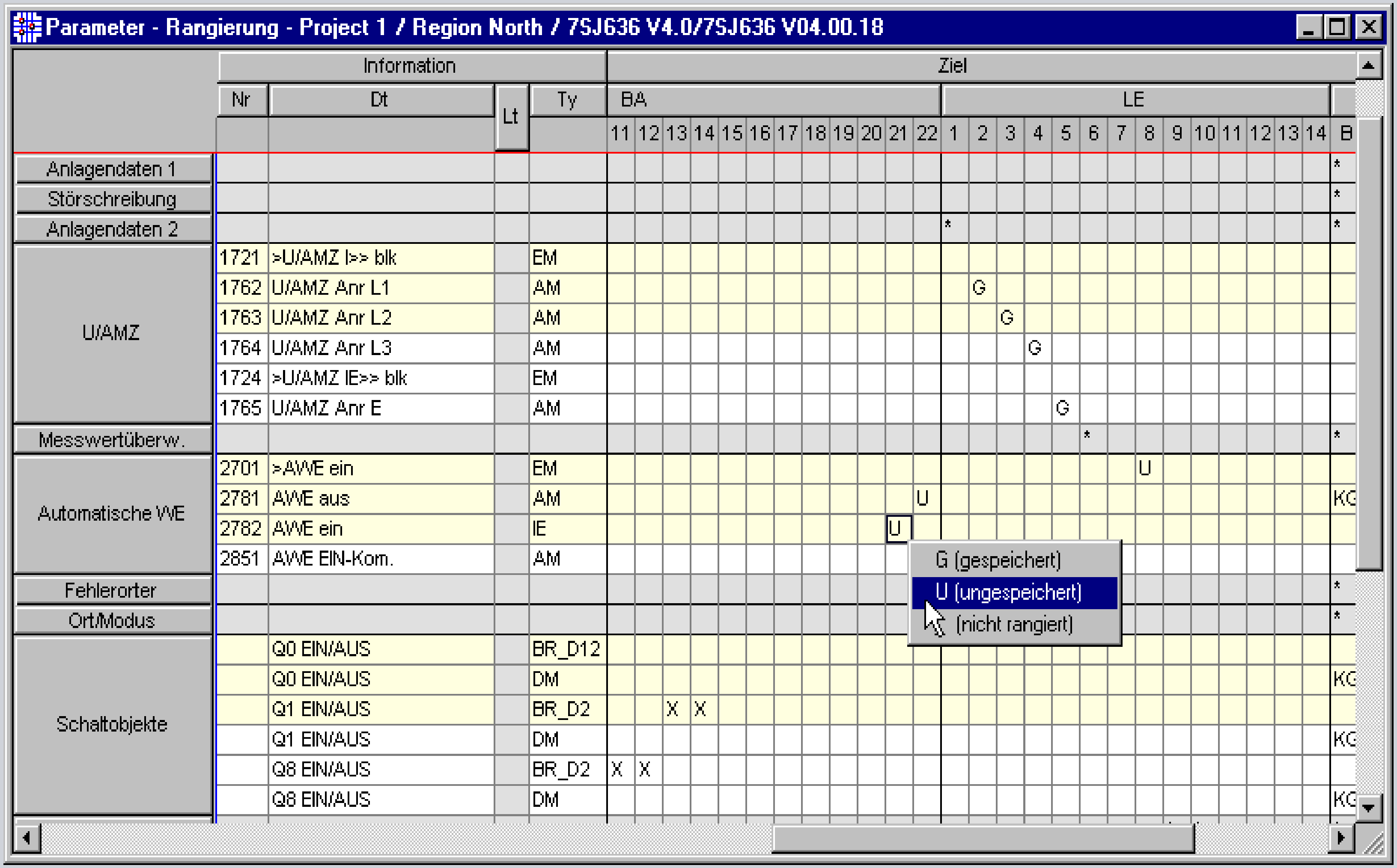


PC controlled relay operation

SIEMENS

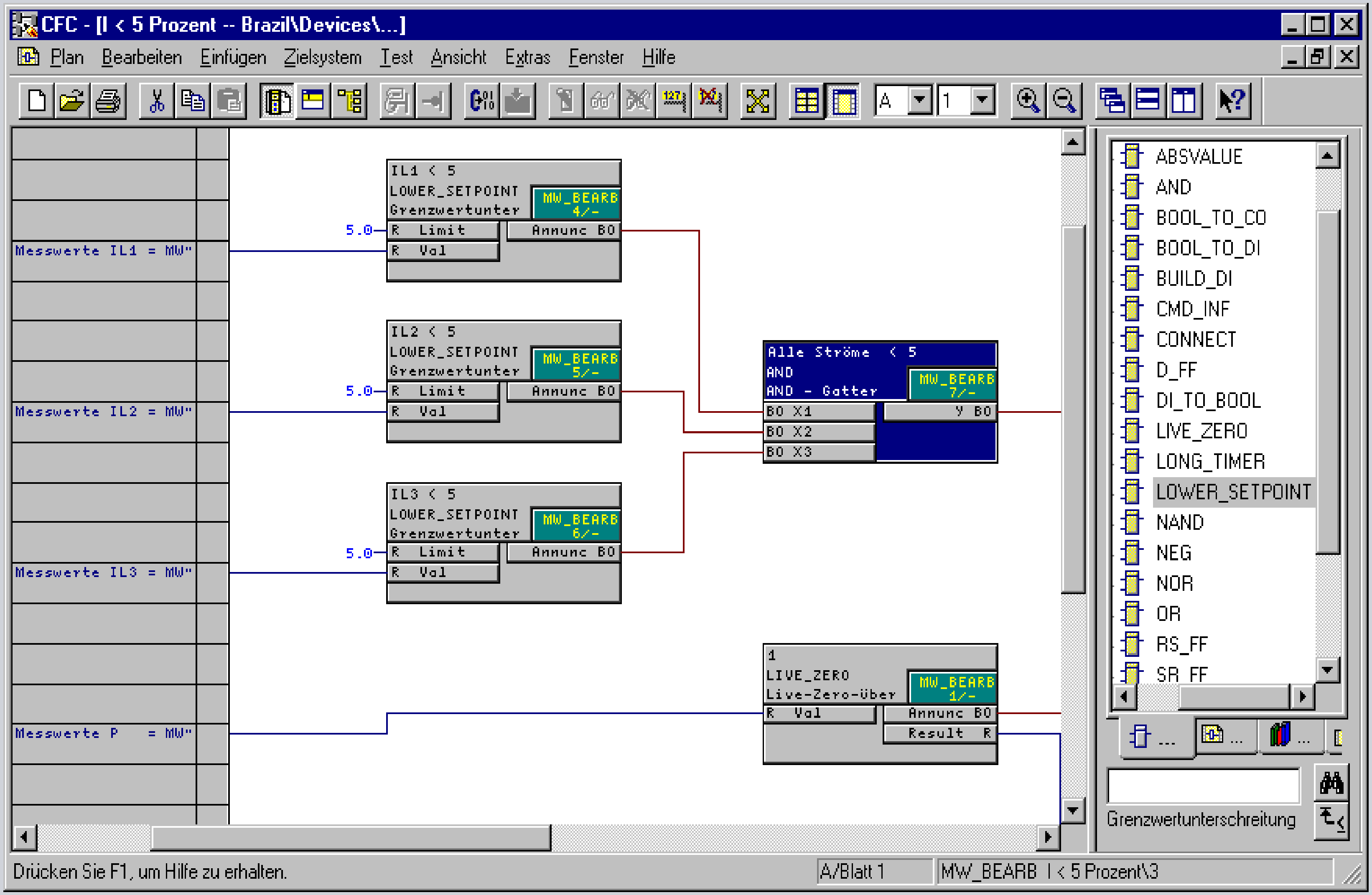


Software marshalling matrix



PLC (Progammable logic control)

SIEMENS



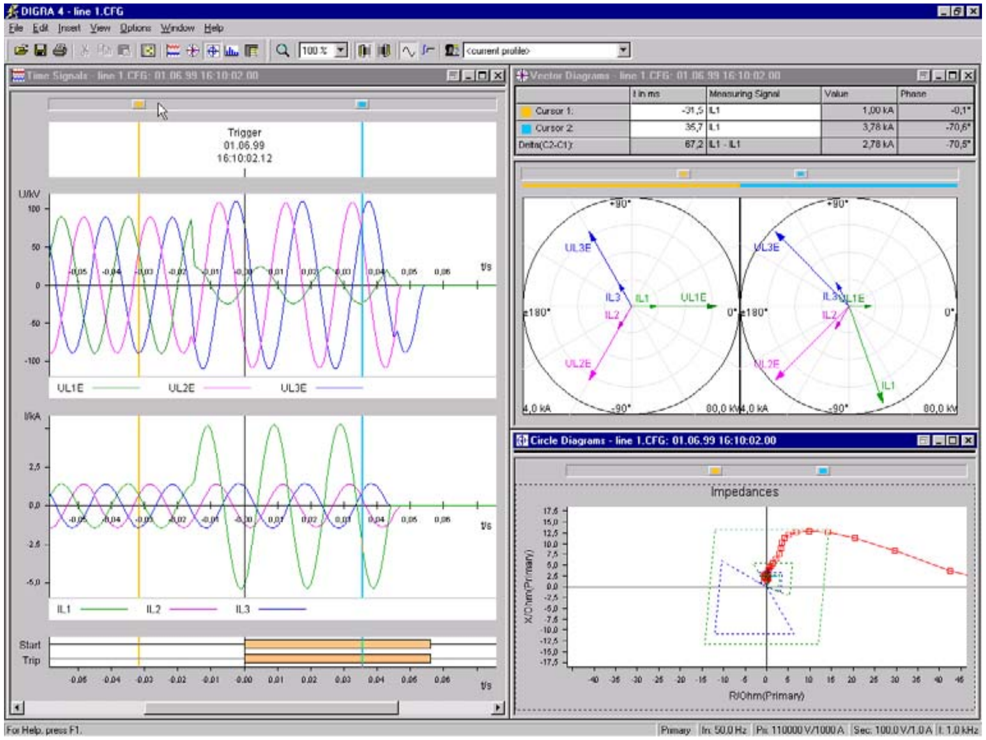
Digital relays: Fault reporting

Detailed information for fault analysis

- Fault history
- Time tagged event recording
- Fault recording
- Distance to fault

➔ Fast fault clearance

➔ Short outage times



SIGRA

Fault analysis Programm

Protection examples

ANSI Device function numbers
(Selection of most important functions)

SIEMENS

51, 51N	Time delayed phase and earth overcurrent protection
50, 50N	Instantaneous phase and earth overcurrent protection
21, 21N	Phase and earth fault distance protection
85	Supplement (Logics) for teleprotection
87	Differential Protection
87N	Earth differential protection (Restricted E/F protection)
27	Undervoltage protection
59	Overvoltage protection
79	Automatic reclosing
81	Frequency protection
49	Overload protection
46	Unbalanced load protection

Line protection, Overview

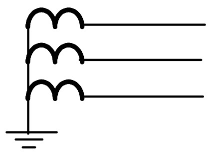
SIEMENS

	OH-lines	Cables
MV:	Radial: **I>, t** (51) Ring: **I>-directional, t** (67) Meshed: **Z<** (21)	**ΔI_L + I>, t** (51) if signalling links available, else as OH-lines
HV:	**Z<** with communication (21) **+ I>-directional, t** (67)	**ΔI_L + Z<** (87) (21) with communication
EHV:	**2 x Z<** (21) + (21) or **ΔI_L + Z<** (87) + (21) each with communication	**ΔI_L + Z<** (87) (21) each with communication

Earth fault protection

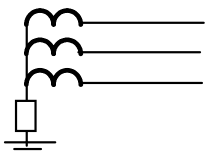
SIEMENS

Solid grounding



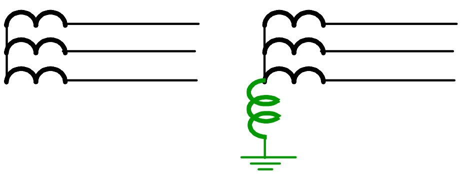
Earth fault current ≈ Phase short-circuit current:
Earth overcurrent, distance, differential protection
Sensivity I_E>: 0.25 to 0.5 x In

Impedance grounded



Same as above
but higher sensivity: 0,1 to 0,2 x In

High impedance grounded



isolated

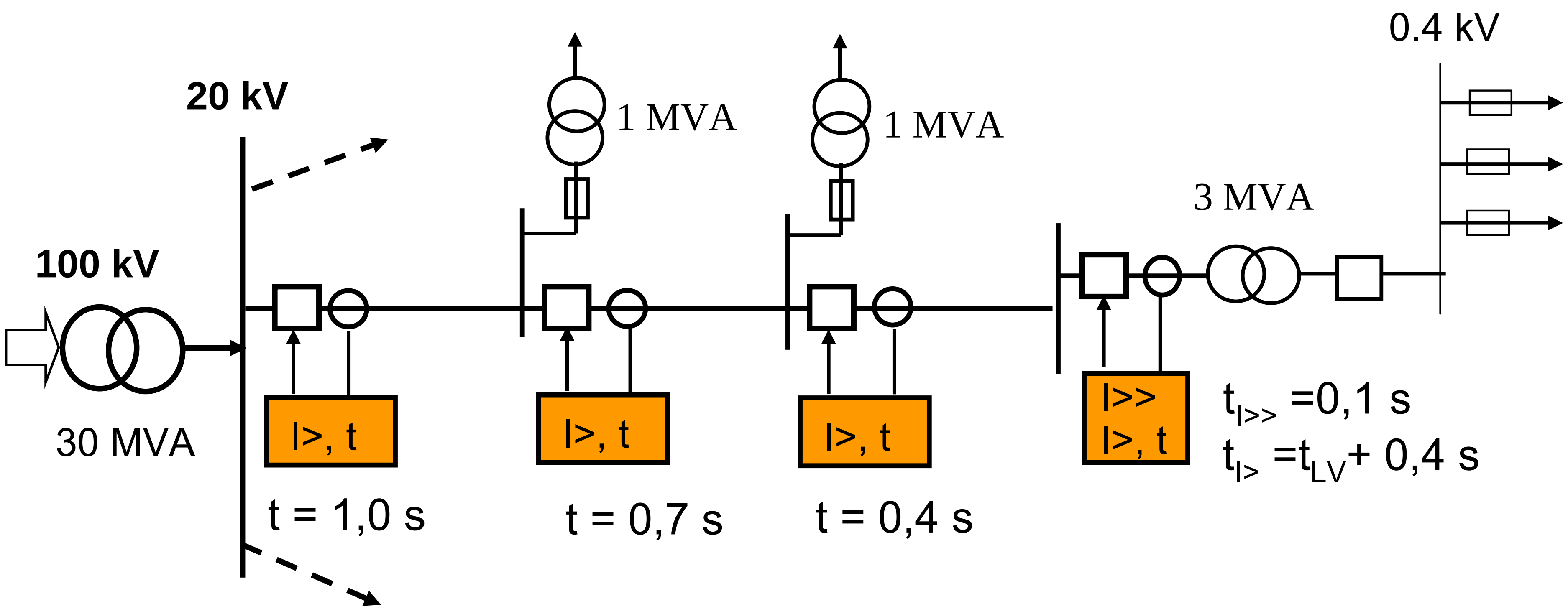
Compensated (Peterson coil)

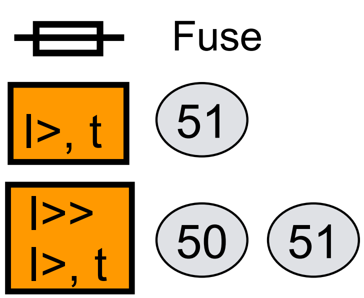
Special earthfault protection necessary!

U_E> for alarming (20 to 50% of $3xU_0$)
Sensitive directional earth current relays (10 to 50 mA)
Core balanced CTs required

Application of Time-Overcurrent Protection

Example: Radial feeders with Definit Time O/C relays

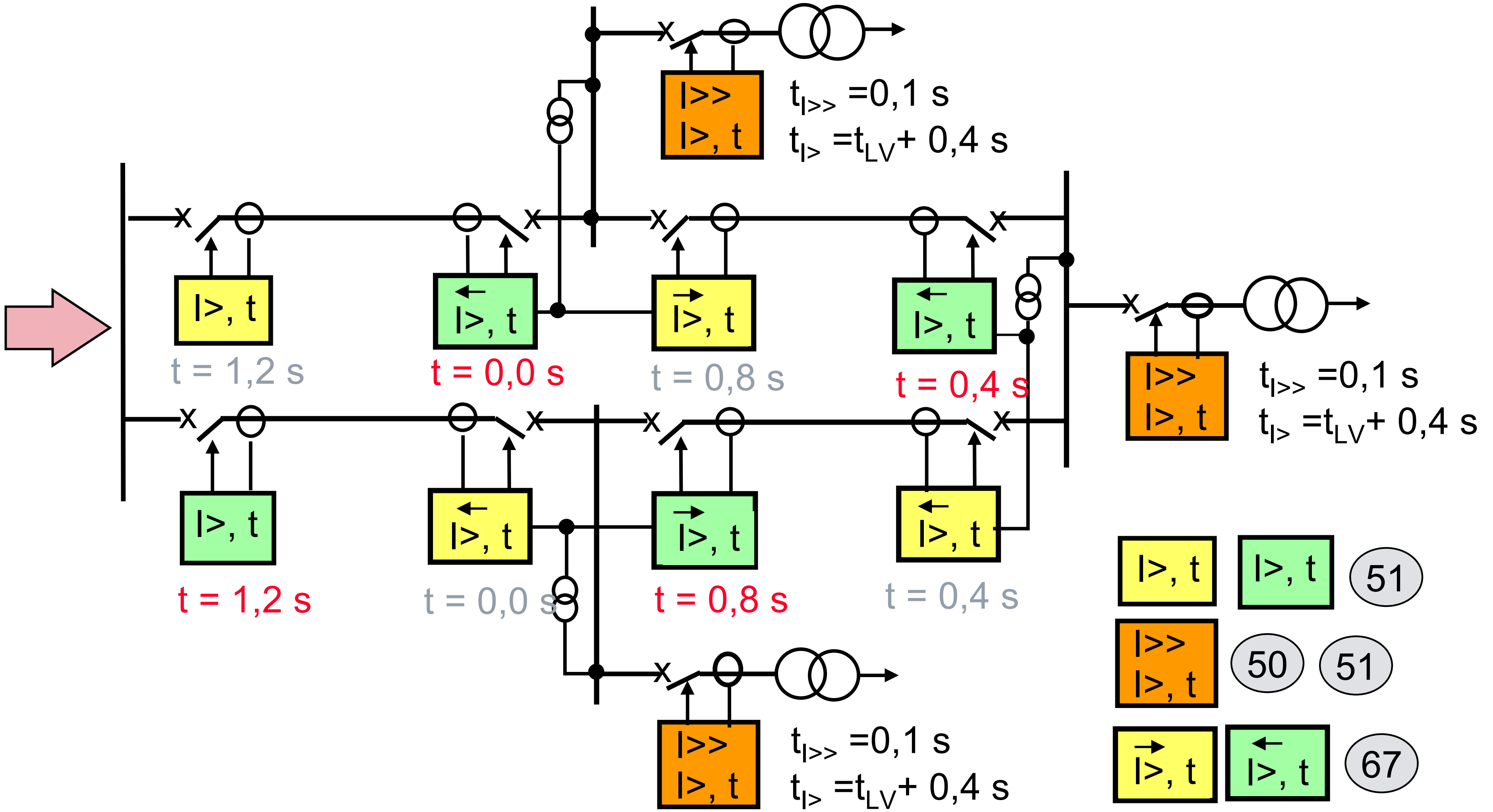




Advantage: Simple relays, no VTs required

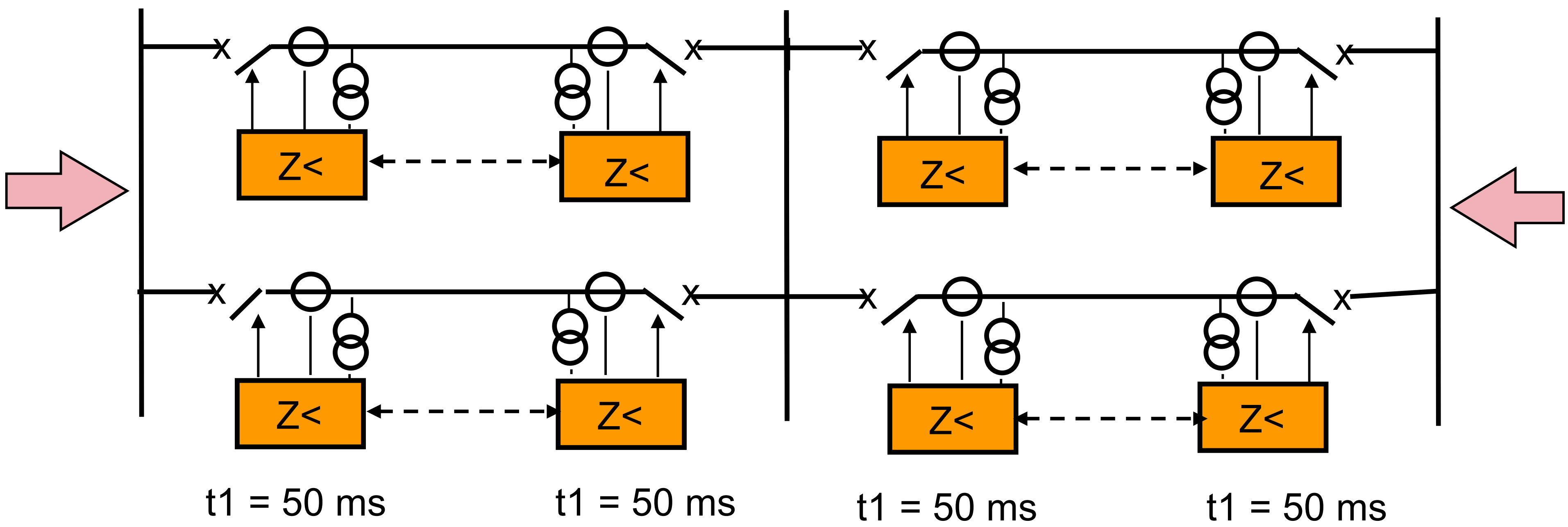
Disadvantage: Tripping time increase in infeed direction

Application of Directional O/C Protection
Example: Ring network



Application of Distance Protection

Example: HV Double circuit lines

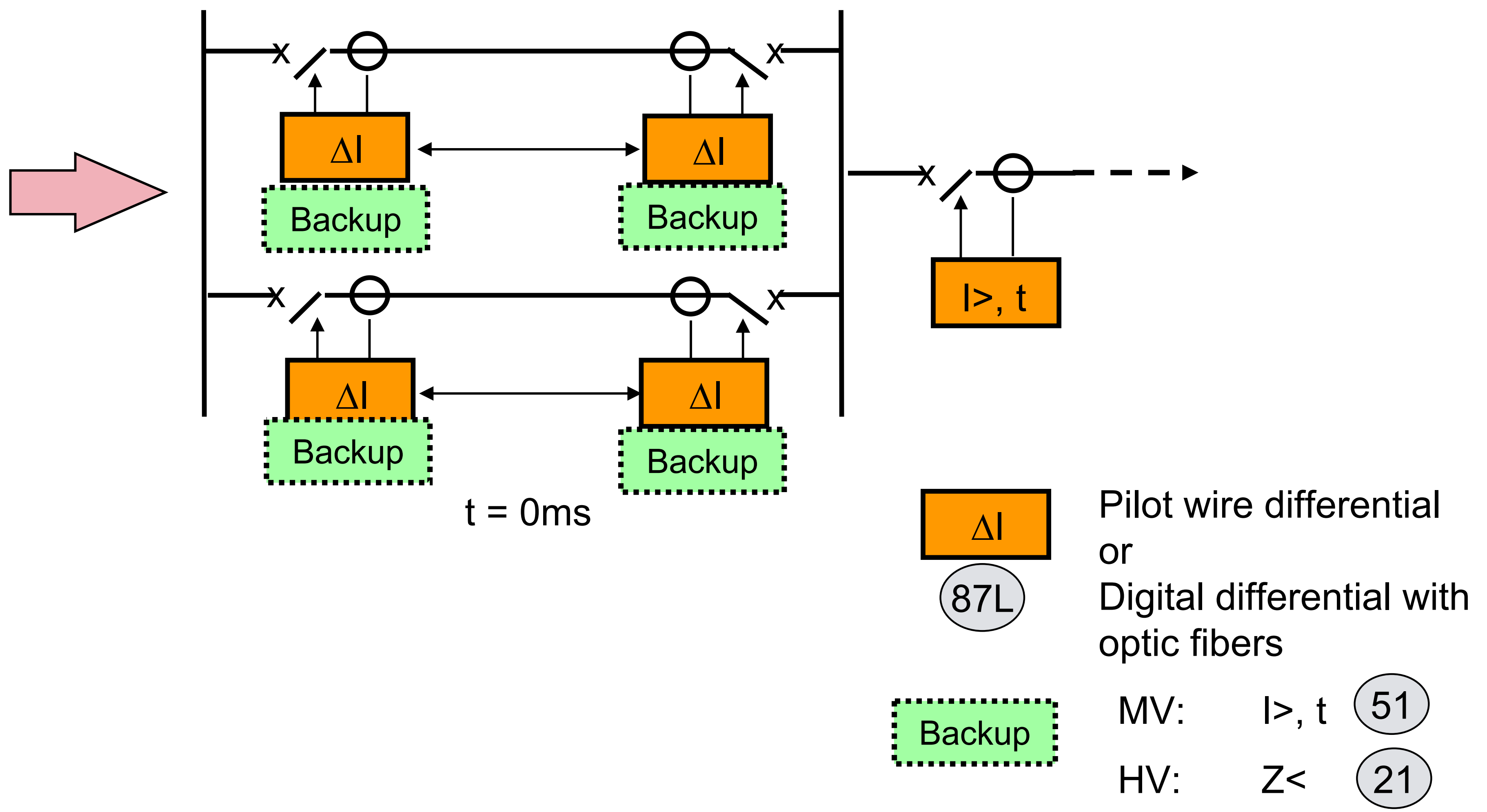


Advantage: Instantaneous fault clearance on protected line and backup for folloeing lines

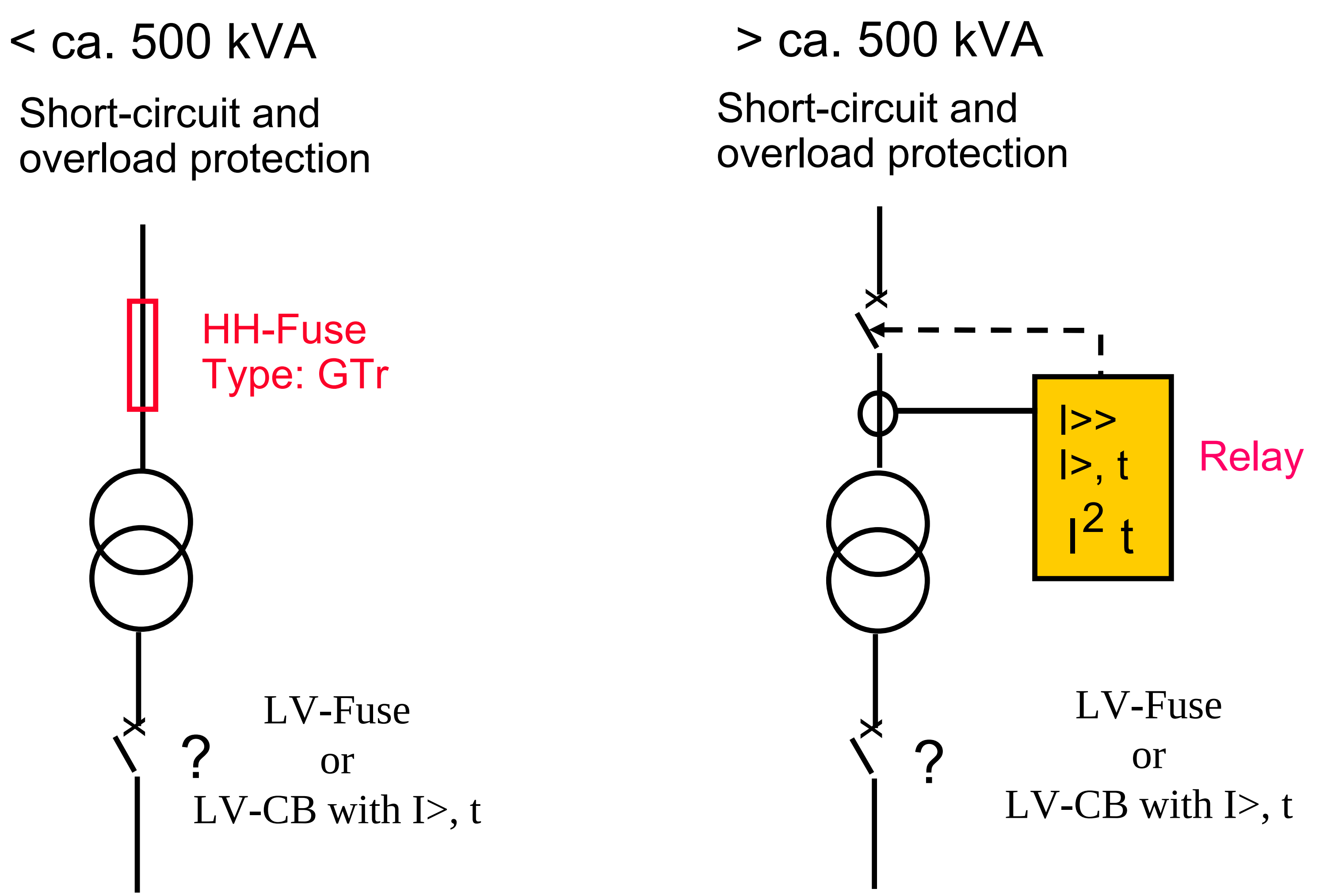
Disadvantage: Higher cost

Application of line differential protection

Example: Cable feeders



Protection of distribution transformers



Protection of larger transformers

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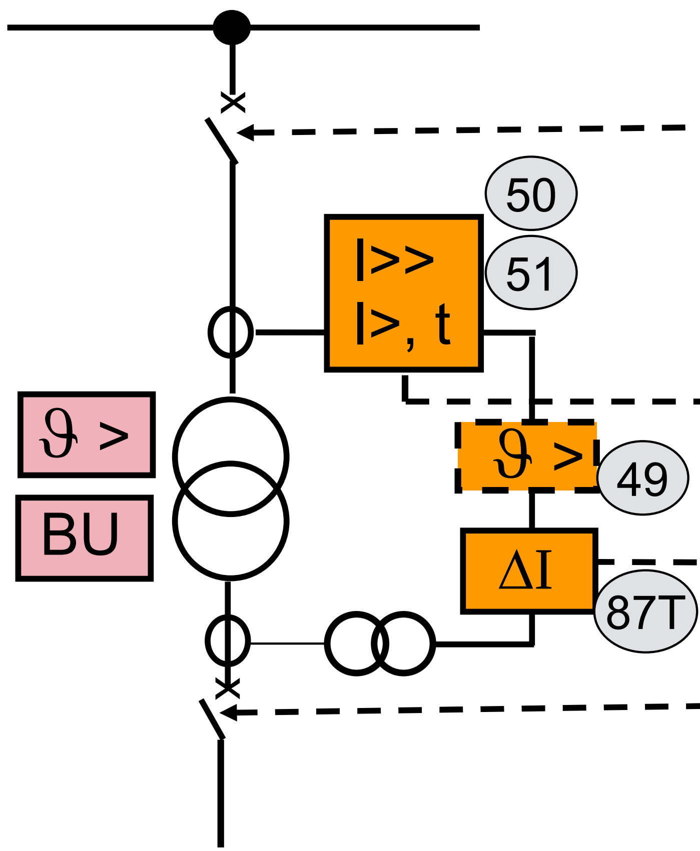

ΔI	Main protection: Current differential
ϑ >	Overload protection
I>, t	Backup protection Time-overcurrent
ϑ >	Thermal monitoring
BU	Gas pressure relay (Buchhulz relay)

Busbar protection

SIEMENS

	Single busbars without feedback	Single busbars with feedback	Multiple busbars
MV:	I>, t with reverse interlocking	Busbar differential	Busbar differential
HV/ EHV:	Busbar differential High impedance type	Busbar differential High impedance type or Low impedance type	Busbar differential Low impedance type

High impedance differential protection requires special Class X current transformers!

Busbar protection
Reverse interlocking method

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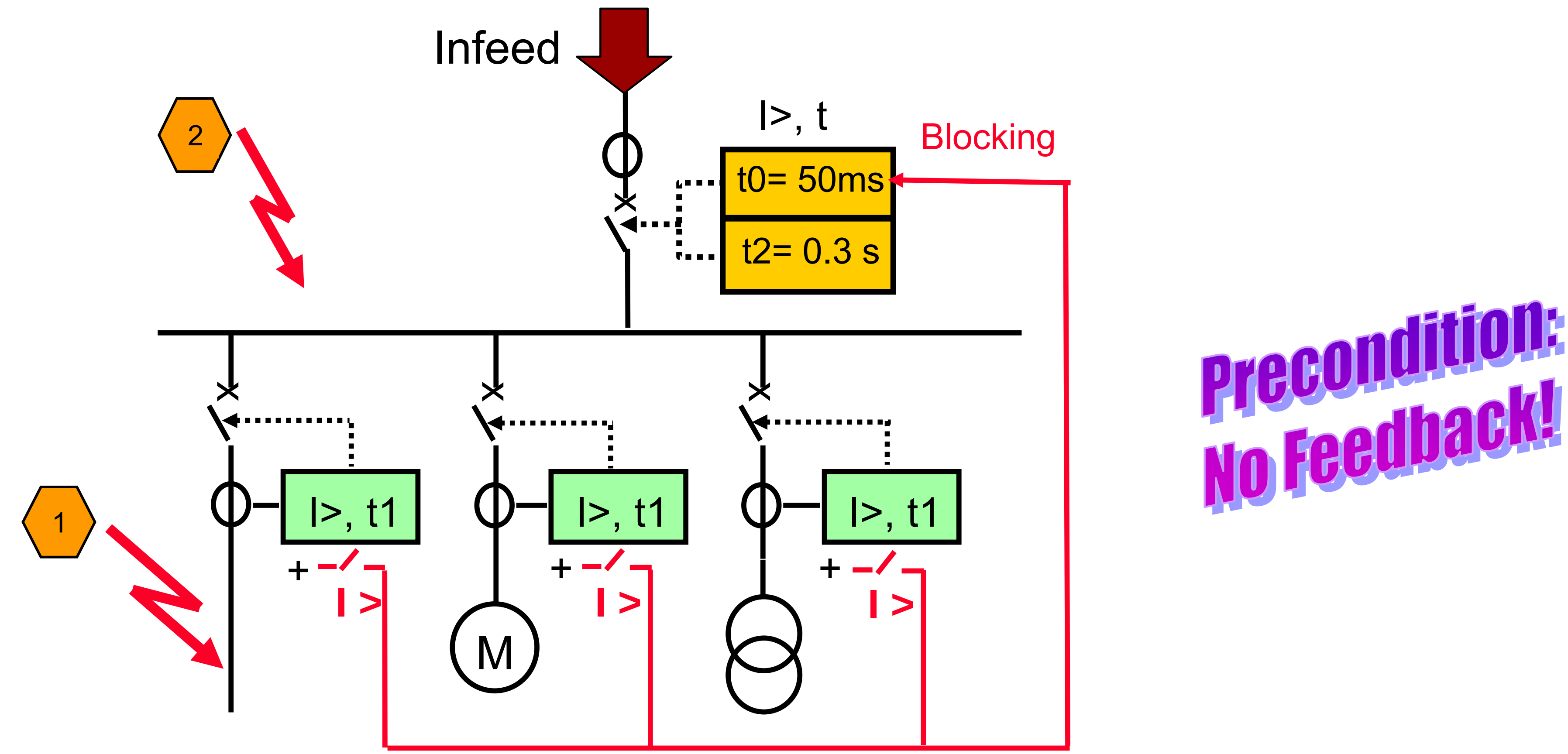

1 Feeder protection blocks 50 ms element of infeed protection and trips faulted feeder

2 Infeed 50 ms step trips bus as there is no protection pick-up in the feeders

Dual service with transformation

Choice of protection ranges

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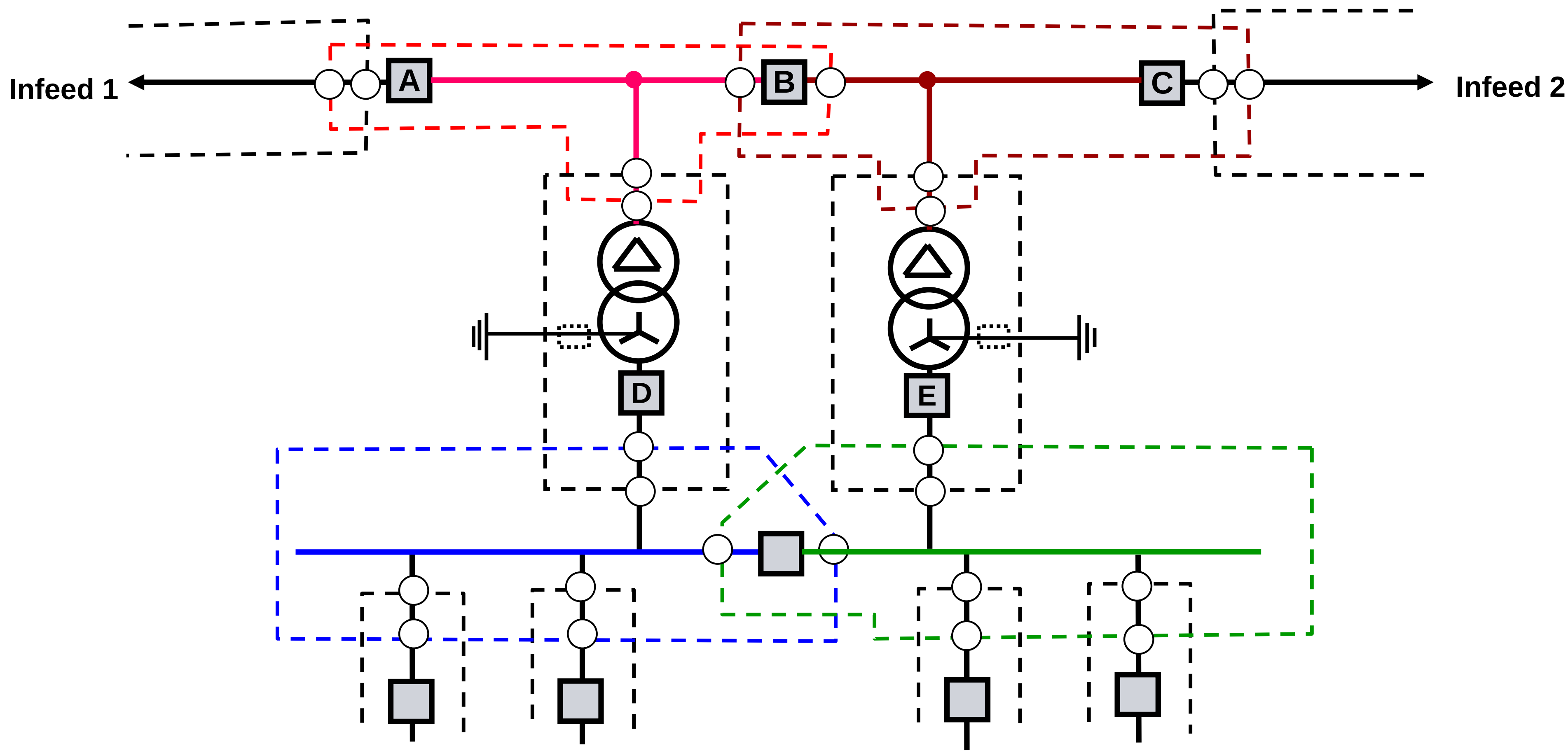

Dual service with transformation

Protection functions